

# Evapotranspiration by Woody Phreatophytes in The Humboldt River Valley Near Winnemucca, Nevada

By T. W. ROBINSON

*With a section on* SOIL-MOISTURE DETERMINATIONS

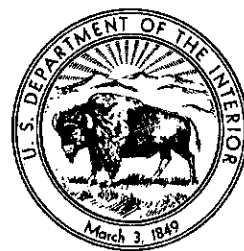
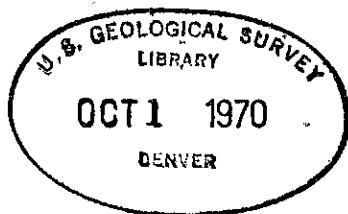
By A. O. WAANANEN

STUDIES OF EVAPOTRANSPIRATION

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GEOLOGICAL SURVEY PROFESSIONAL PAPER 491-D

*Quantitative studies of water use  
by greasewood, rabbitbrush,  
willow, and wildrose*



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## STUDIES OF EVAPOTRANSPIRATION

# EVAPOTRANSPIRATION BY WOODY PHREATOPHYTES IN THE HUMBOLDT RIVER VALLEY, NEAR WINNEMUCCA, NEVADA

By T. W. ROBINSON

### ABSTRACT

This report presents the results of cooperative studies of evapotranspiration by phreatophytes in the Winnemucca reach of the Humboldt River valley. Water that is wasted by evapotranspiration from areas of low beneficial phreatophytes is one of the largest unknowns in the water budget of the reach. In order to obtain information with which to evaluate the consumptive waste, studies of the water use of four woody phreatophytes—greasewood, rabbitbrush, willow, and wild-rose—were undertaken in evapotranspiration tanks at the Winnemucca test site.

Twelve tanks ranging in size from 30 feet square and 10.5 feet deep to 10 feet square and 7 feet deep were constructed. Seedlings of greasewood were planted in 2 tanks and rabbitbrush in 3 tanks; cuttings of willow were planted in 3 tanks and wild-rose in 3 tanks. The twelfth was left bare. The tanks were constructed in place by lining excavated pits with watertight plastic membranes, providing a water-distribution system on the bottom and backfilling with the excavated material. The tanks were operated during the growing season April 1 to October 20 from 1961-67, inclusive. Water metered into elevated reservoirs was supplied by gravity to the evapotranspiration tanks.

Evapotranspiration by the plants was computed as the sum of rainfall, soil-moisture depletion and water supplied to the tanks during the growing season. Plant growth and development were recorded by photographs and transects. Foliage volumes were computed from the transect data as the product of the average height, the cover density of the plants, and the area of the tank.

Foliage volumes and water use were affected by difference in depths to the water level, damage to the plants by rabbits and by insects, and, for the greasewood and rabbitbrush, by accumulation of boron in toxic concentrations in the root zone. The damages were alleviated by removing rabbits from the test site, by spraying the insect-infested plants, and by reducing the boron content in the root zone by backwash leaching.

Boron content of undisturbed soil, adjacent to the greasewood tanks, ranged from 13 to 32 milligrams per kilogram in the top 1.5 feet, and from 5 to 0.9 milligrams per kilogram between 5 and 9 feet. Green greasewood leaves had a boron content that ranged from 196 to 233 milligrams per kilogram.

Evapotranspiration by a given species of phreatophytes is affected by climatic conditions, of which temperature is the most important. Water use by greasewood and rabbitbrush in April was only about 2 percent of the yearly total, whereas during the months of peak use it was 28 percent. More than two-

thirds of the annual use occurred during June, July, and August.

Evapotranspiration, expressed on an areal basis as depth over a unit area, gives no indication of growth conditions for which the information was obtained and may result in serious error when transposed to areas of dissimilar growth conditions. Some of the difficulties and uncertainties of the areal method may be avoided by expressing evapotranspiration on a volume-of-foliage basis, as a quantity of water per unit of foliage volume. The method presumes that transpiration by a species is proportional to the total transpiring leaf area, and so proportional to the foliage volume. In the results of the studies, evapotranspiration is expressed in both quantities. The annual use of water ranged rather widely over the study period, as the plants responded to the effect of plant damage, boron toxicity, depth to the water level, and warmth and length of the growing seasons. Draft from the water table, equivalent to the water supplied to the tanks, varied with the rainfall. It was greatest when rainfall was scant, and least when the rains were copious.

### INTRODUCTION

The Humboldt River Research Project is a Federal-State cooperative project concerned with developing data and techniques by which to evaluate the water resources of the Winnemucca reach of the Humboldt River. The agencies cooperating in the study were the U.S. Geological Survey, the U.S. Bureau of Reclamation, and the Department of Conservation and Natural Resources of the State of Nevada.

The Winnemucca reach extends from the Comus gaging station downstream to the Rose Creek gaging station. The Comus gage is about 23 miles east, and the Rose Creek gage is about 15 miles southwest of the city of Winnemucca. The distance between the stations along the meanders of the river in the flood plain is about 92 miles, whereas the distance along the meandering flood plain is about 45 miles. The flood plain ranges in width from 0.2 to 5 miles; the average width is 0.8 mile. The altitude at the Comus gage is slightly less than 4,400 feet above mean sea level, and that at the Rose Creek gage is about 4,200 feet (fig. 1).

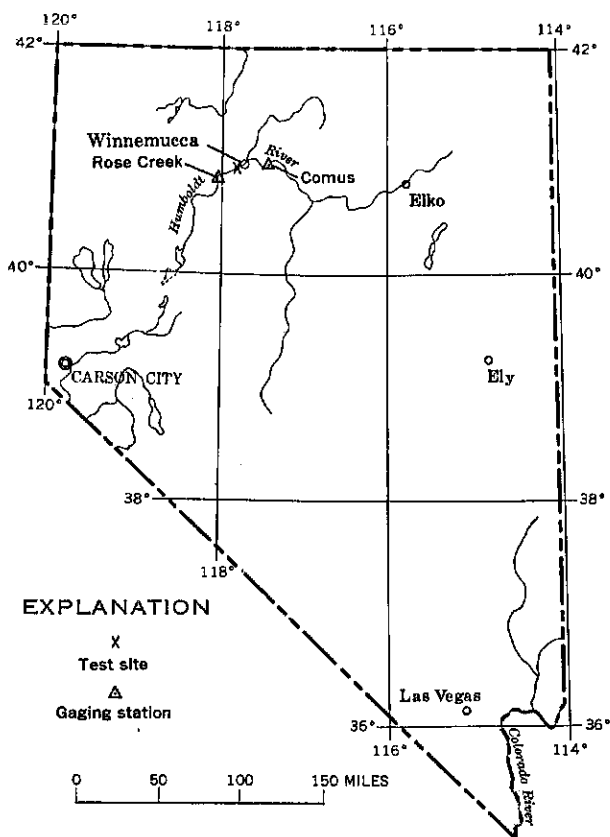


FIGURE 1.—Location of Humboldt River Research Project test site.

One of the largest unknowns in the water budget for this reach of the Humboldt River is the evapotranspiration loss. This loss includes the losses from water and bare-soil surfaces by evaporation and losses from soil moisture and ground water through transpiration by phreatophytes. Phreatophytes are plants that habitually send their roots to the water table, and obtain their water supply primarily from ground water. Several species of woody phreatophytes thrive along the streambanks, in the flood plain, and on the lower parts of the adjacent alluvial fans. Water use by such plants is by far the largest of the several evapotranspiration losses.

The purpose of this study, one of several in the inter-agency Humboldt River Research Project, was to determine the water use by woody phreatophytes, notably several species of low beneficial use. The water used by these plants constitutes a consumptive waste of water, for it is discharged into the atmosphere with but little benefit to man. This is one of nature's preemptive taxes, and results in depletion of the water resources of a region and reduction in the quantity of water available to man. With proper management, man can reduce this draft and benefit from the reduced draft to the extent of the salvageable portion. Possible modifications might

be to replace the phreatophytes of low economic value with plants of higher economic value or to salvage the water otherwise consumptively wasted and use it beneficially. To assess the economic feasibility of such operations, quantitative evaluations of the consumptive waste are needed.

#### PURPOSE AND SCOPE

The purpose of the evapotranspiration studies was to obtain data for evaluation of the consumptive use of water by four woody phreatophytes widespread in the Winnemucca reach. These shrubs occur generally throughout the Humboldt River basin and in other areas in Nevada. The studies involved growing the plants in large evapotranspiration tanks and determining their seasonal water use for different depths to the water level and for different cover densities. The first tanks were constructed at the Winnemucca test site (see page D4) in the fall of 1959 and were planted in the spring of 1960. Later plantings were made in 1961 and 1962 as additional tanks were constructed.

#### ACKNOWLEDGMENTS

Funds for construction of the tanks and for part of the operation and maintenance costs were provided by the U.S. Bureau of Reclamation. The evapotranspiration studies were under the technical direction of the Water Resources Division, U.S. Geological Survey.

The cooperation and assistance provided by personnel of the Nevada Department of Conservation and Natural Resources are acknowledged. The author is especially grateful to George Hardman, Assistant Director, for his unflagging interest, his counsel and helpful suggestions. Vernon Laca, assisted at times by James Starr, provided 7-day-a-week operation of the tanks during the growing season. The wholehearted cooperation of Mr. and Mrs. H. T. Harrer, on whose property the Winnemucca test site and access road are located, is appreciated and acknowledged.

#### CLIMATE

The Winnemucca reach of the Humboldt River lies largely in the 5- to 8-inch rainfall zone. The climate is characterized by few cloudy days and moderate wind movement and may be classified as arid to semiarid. About two thirds of the annual precipitation falls as rain or snow during the winter period, December to May. During the growing season, April to October, the precipitation falls largely as scattered summer showers that occasionally exceed one-half inch. On rare occasions as much as 1 inch of rain has been recorded during a single storm. The prevailing winds are westerlies, and these lose much of their moisture as they pass over the Sierra Nevada about 150 miles to the west.

The summers are marked by warm days and cool nights. Temperatures tend to rise sharply with the sunrise and remain comparatively high during the daylight hours, then drop rapidly about sundown. A daily temperature variation of 50°F is not uncommon. According to the U.S. Weather Bureau, the average monthly temperature during the growing season for 92 years of record at and near Winnemucca has ranged from 47.1°F in April to 71.7°F in July. Extremes of temperature have ranged from 36°F below zero in January to a high of 108°F in July. Temperatures rise to 100°F or more on the average of 2 days a year. The growing season during the 92-year period of record has varied considerably, the shortest on record being only 63 days and the longest 184 days; the average growing season is about 140 days.

Measurements of pan evaporation for the months of April through October were made at the Winnemucca test site from 1962 through 1967. Evaporation during this 6-year period ranged from 52.7 inches in 1965 to 66.8 inches in 1966 and averaged 58.0 inches.

#### SPECIES OF WOODY PHREATOPHYTES

The common woody phreatophytes that are native to the Winnemucca reach of the Humboldt River include greasewood (*Sarcobatus vermiculatus*), rabbitbrush (*Chrysothamnus*), and willow (*Salix*). Wildrose (*Rosa*) and buffaloberry (*Shepherdia*) occupy less extensive areas. Saltcedar (*Tamarix*), an exotic plant from the Mediterranean area introduced into this country about the turn of the century, is invading the lower part of the Winnemucca reach. Saltcedar is also grown as an ornamental shrub in several places in the city of Winnemucca. In addition, hydrophytes, such as cattails and bullrushes, grow in several small areas adjacent to the river.

Greasewood is the most extensive phreatophyte in the area, and willow and rabbitbrush are the next most common species. The open spaces on the bottom lands of the flood plain are covered with a variety of beneficial phreatophytic grasses. The two common species are bluejoint or creeping wildrye (*Elymus triticoides*) and saltgrass (*Distichlis stricta*). Great Basin wildrye (*Elymus cinereus*) was once common in the flood plain, but is now found only in areas protected from heavy livestock grazing.

#### WINNEMUCCA TEST SITE

The Winnemucca test site is a parcel of land 300 by 600 feet on the Harrer ranch, in the NE¼ sec. 2, T.35, R.37 E., Mount Diablo base line and meridian, on the south side of the Humboldt River. The site is 3¼ miles southwest of Winnemucca, and three-fourths mile

west of U.S. Highway 40. About half the site lies on the present flood plain of the Humboldt River, and the remainder on a terrace about 4 feet higher. Both parts are nearly flat, with some slope northward toward the river. The terrace is at an altitude of about 4,260 feet.

To prevent inundation of the part of the test site on the flood plain during periods of high water in the Humboldt River or when the adjacent flood plain is ponded for flood irrigation, an earthen dike, approximately 2½–3 feet high, was constructed. The site also was fenced with a combination of barbed wire and wire mesh, which was ostensibly rabbit tight and stock proof.

The layout of the test site, showing the evapotranspiration tanks, water-supply reservoirs, pipelines, supply well, and weather station, is shown in figure 2.

#### WEATHER STATION

A class "A" weather station, installed at the test site in March 1962, was operated each season during the period April 1 to November 1. Instrumentation consisted of a 4-foot evaporation pan, a totalizing anemometer, maximum and minimum thermometers, hygrothermograph, and an 8-inch rain gage. The temperature and humidity instruments were housed in a cotton-region type shelter. A pyrheliograph for measuring incoming radiation was installed in the low-lying meadow a short distance from the weather station.

In addition, a thermograph was installed at greasewood tank 2 to measure the surface temperature of the soil in the tank. The sensing element was covered with about one-fourth inch of soil, enough for shielding from the direct rays of the sun. All the nonrecording instruments were read daily, and the charts on the recording instruments were changed weekly. The station is about 30 feet lower in altitude than the Weather Bureau station at the Winnemucca Airport, 3 miles to the south.

#### EVAPOTRANSPIRATION STUDIES

##### DEFINITION OF EVAPOTRANSPIRATION

The first use of the term "evapo-transpiration" was by Sondregger (1929) in May 1929; he used it as a synonym of evaporation-transpiration losses, a term coined by Lee (in Lee and others, 1926) to describe water lost to the atmosphere. Later in the 1930's as the term came into common usage the hyphen was omitted. The term is generally considered to be synonymous with the term "consumptive use" and is defined in Manual No. 43, "Nomenclature for Hydraulics," of the American Society of Civil Engineers (1962, p. 156) as "water withdrawn from soil by evaporation and plant transpiration."

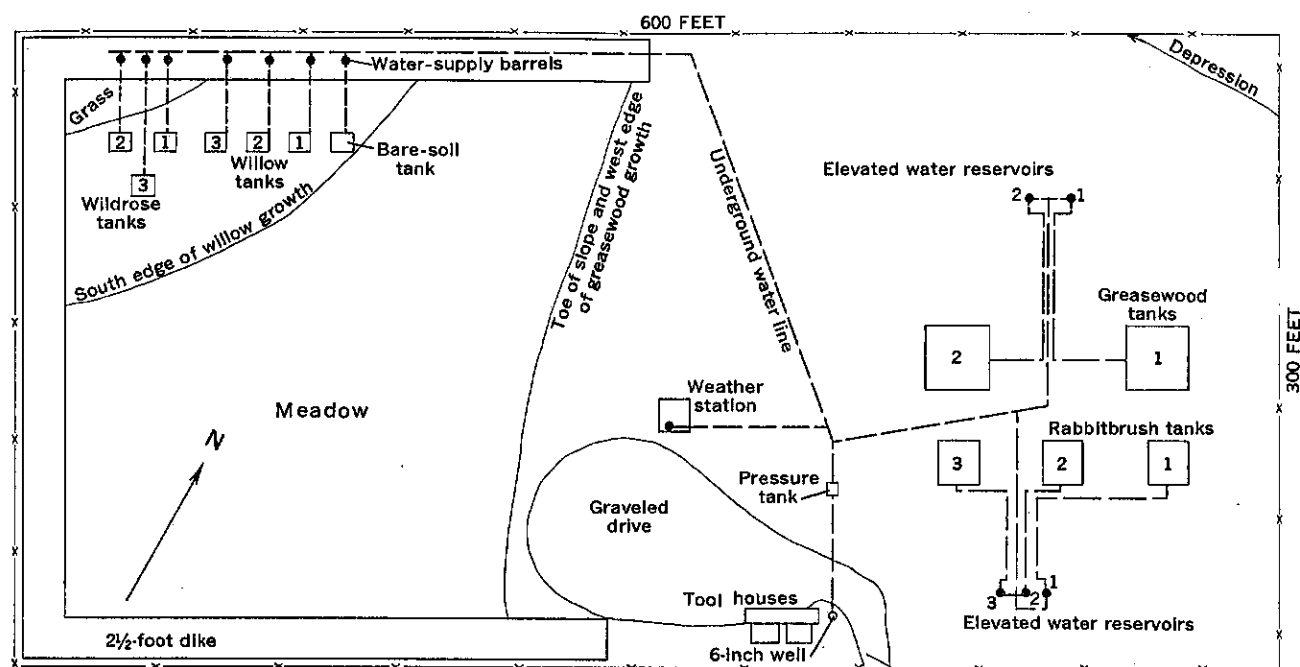


FIGURE 2.—Humboldt River Research Project evapotranspiration test site.

### EVAPOTRANSPIRATION TANKS

Twelve evapotranspiration tanks were installed at the Winnemucca test site. Eleven tanks were used to measure the evapotranspiration from four species of woody phreatophytes—greasewood, rabbitbrush, willow, and wildrose—and the twelfth was used to measure the evaporation from bare soil. The plant species, tank sizes, and planting dates are given in the following tabulation:

*Evapotranspiration tanks*

Plant species	Tanks		Date planted
	Number	Size (ft)	
Greasewood.....	2	30×30×10.5	Apr. 13, 1960.
Willow.....	3	10×10×7.5	Apr. 14, 1960.
Wildrose.....	3	10×10×7.0	May 20, 1961.
Rabbitbrush.....	3	20×20×10.0	Apr. 10 and 11, 1962.
Bare soil.....	1	10×10×7.0	

The greasewood and rabbitbrush tanks are on the terrace at the test site, and the willow, wildrose, and bare-soil tanks are on the low-lying flood plain. The terrace, according to Cohen (1965, p. 28, pl. 1), consists of deposits of Quaternary age, whereas the flood plain consists of deposits of Holocene (Recent) age. The soils and vegetation in the two parts are quite different. The terrace deposits consist of poorly sorted gravel, sand, silt, and clay, whereas the flood-plain deposits consist of clay loam with considerable organic matter and occasional balls of volcanic ash. The terrace deposits support a vigorous and well-established

growth of greasewood that averages 2.5 feet in height; individual plants are as much as 5 feet high. Saltgrass grows in open spaces between the clumps of greasewood. About three fourths of the flood-plain part of the test-site meadowland is covered with several kinds of grasses, and about one fourth, in the northwest corner of the site, has a dense growth of willows and wildrose. The willow and wildrose tanks are in this northwest corner. The bare-soil tank is in the meadow-grass area, at the edge of the willow growth. Saltgrass occurs among the willows and also in the meadow. The predominant meadow grass, however, is bluejoint or creeping wildrye. As the result of the fencing of the site for protection from grazing, a few clumps of Great Basin wildrye have made a healthy growth in the meadow.

### CONSTRUCTION OF EVAPOTRANSPIRATION TANKS

The tanks were constructed in place by installing watertight plastic-membrane linings in pits excavated into the terrace and flood-plain deposits. The membranes for the 30- by 30-foot tanks and the 10- by 10-foot tanks were fabricated in sheets 57 and 30 feet square, respectively, from black polyvinyl plastic sheets 20 mils (0.02 inch) thick. The plastic sheets for the 20- by 20-foot tanks were 45 feet square and were fabricated from aqua polyvinyl material 22 mils thick.

The pits for the tanks were excavated to the water table and were 2-3 feet larger than the finished size. Excavation was done by a dragline equipped with a 1-yard bucket. When the excavation was completed, the bottom of the pit was leveled manually, raked clean of

stones and sharp objects, and shaped to size. Next, the dimensions of the finished tank were outlined on the bottom of the pit by using 1×12-inch boards placed on edge, and the plastic membrane was positioned in the bottom of the pit as shown in figure 3. Marks on the center of the membrane served as guides to fix the liner position in the pit. After the membrane was positioned, the part forming the bottom of the tank as outlined by the 1×12-inch boards was covered with a 4–5-inch layer of pit-run medium to coarse sand. A water-distribution system was then placed on the sand layer as shown in figure 4. The system consisted of a horizontal E-shaped component made of 2-inch rigid plastic pipe perforated with  $\frac{3}{16}$ -inch holes on 14-inch centers on the underside, and a 4-inch riser pipe for adding or withdrawing water from the system. The riser pipe extended 0.5 foot above the ground surface and was also used to monitor the water level in the tank. A plan and section view of the tank, including the water-distribution system, is shown in figure 5. The 2-inch pipes were covered with sand throughout their perforated sections in order to facilitate movement of water into the sand layer which has been described.

With the water-distribution system in place, the pit was backfilled with the material previously excavated, a clamshell bucket being substituted in place of the drag-line bucket for this purpose. The excavated material was replaced only approximately in the reverse of the order in which it had been removed. The positioning of the membrane for the sides of the tank was accomplished by alternately draping the membrane on the outside of the 1×12-inch boards and placing fill on the inside, and then draping on the inside and placing fill on the outside. As the level of the fill on both sides became even with the top of the boards, the boards were raised 8–10 inches and the backfilling process repeated. Thus, as the backfilling progressed, the membrane that was origi-

nally draped over the 1×12-inch boards in the bottom of the pit became the sides of the tank. Experience demonstrated the advantages of keeping the backfill higher along the sides than in the center of the tank, and the desirability of fastening the membrane corners on the land surface at the corners of the pit as shown in figure 6. The 30- by 30-foot and the 20- by 20-foot tanks were constructed in the fall of the year. Upon completion, the tanks were tested for watertightness by being filled with water to within about 4 feet of the surface and allowed to stand in this condition during the winter months. No leaks developed. A 30- by 30-foot tank was constructed in about 4 days; the excavation required about 1½ days; the installation of the membrane, water-distribution system, and the backfilling about 2½ days. The smaller 20- by 20-foot tanks were constructed in 2½ days each, with the excavation usually completed in about 7 hours; the 10- by 10-foot tanks required 1–1½ days each.

The method of construction and the design of the water-distribution system in the shallower 10- by 10-foot tanks was different from that for the larger tanks. For the smaller tanks, the pit was excavated to the finished size, and the membrane suspended loosely from the top edges of the pit. During backfilling, care was taken to keep the membrane on the sides of the pit loose and free from tension. The distribution system resting on a 4- to 5-inch layer of sand, as shown in figure 7, was an 8-foot circle of 2-inch flexible plastic pipe that was cross connected on one diameter, perforated on the bottom, and connected to a 6-inch riser pipe.

#### WATER-SUPPLY SYSTEM

Water for use in the test site was obtained from a drilled well, 25 feet deep, located inside and near the entrance to the site (fig. 2). The well was equipped with an electrically operated jet pump that delivered water under a working pressure of 30 pounds per square inch



FIGURE 3.—Installation of a plastic membrane liner in a 30- by 30-foot evapotranspiration tank: 1 × 12-inch boards on edge outline the sides of the tank.

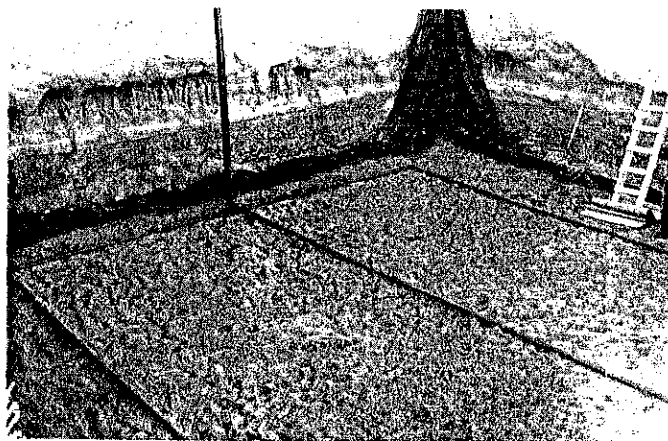


FIGURE 4.—The bottom of the tank in figure 3 showing the water-distribution system in place.

## STUDIES OF EVAPOTRANSPIRATION

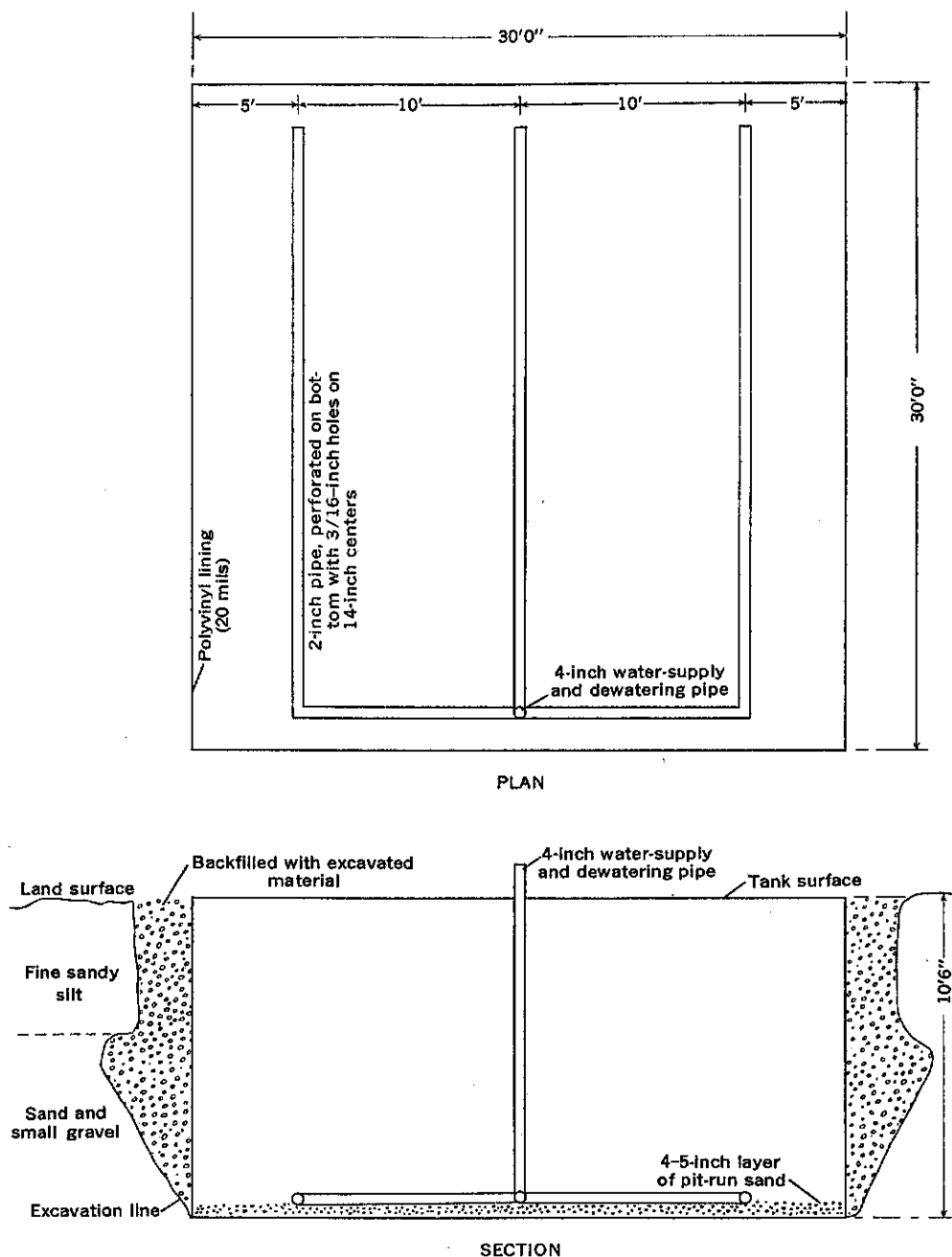


FIGURE 5.—Plan and section of evapotranspiration tank showing water-distribution system.

to a 500-gallon buried pressure tank. Water from the pressure tank was delivered through a pipeline to elevated metal reservoirs adjacent to the evapotranspiration tanks (fig. 8). The pipeline consisted of about 500 feet of  $\frac{3}{4}$ -inch iron pipe and 400 feet of 1-inch plastic tubing.

The volume of water delivered to the reservoir was measured by industrial cold-water meters that have horizontal nonsetback-reading registers and a 10-gallon

dial circle calibrated to one-fourth gallon. Each meter was tested for accuracy before installation; for flow rates greater than 3 gallons a minute, the measurement error was found to be less than 1 percent.

Water from the reservoir was delivered by gravity through a  $\frac{3}{4}$ -inch pipeline to a float-controlled valve at the 4-inch supply pipe (fig. 5) of the evapotranspiration tank. Water levels in the evapotranspiration tanks were controlled by means of a  $3\frac{1}{2}$ -inch float in the

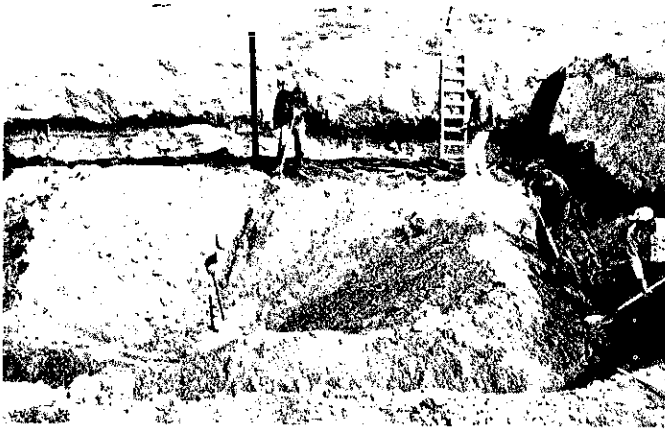


FIGURE 6.—A 30- by 30-foot tank about half completed, with the corners of the membrane fastened at the land surface. The photograph shows the method of backfilling.



FIGURE 7.—Installation of the water-distribution system in a 10- by 10-foot evapotranspiration tank.

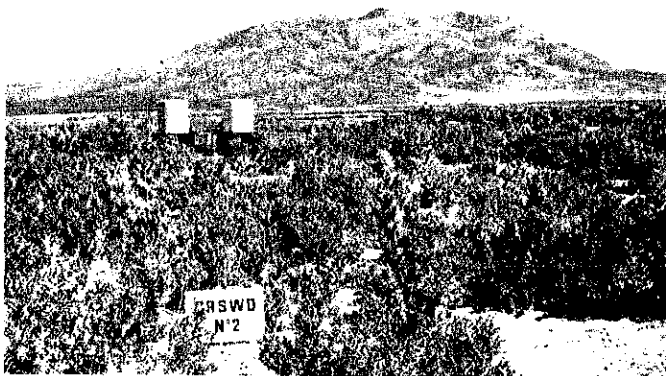


FIGURE 8.—The 5-year-old greasewood plants in tank 2 and the two 350-gallon elevated reservoirs that supply water to greasewood tanks 1 and 2.

supply pipe that was directly connected by a  $\frac{3}{16}$ -inch rod to the float-valve mechanism. The float valve was activated by the float; as the water level in the evapotranspiration tank fell, the valve opened to admit water; when the water level rose, the valve closed. The interval between the high and low position of the water levels was less than 0.1 foot; so a nearly constant water level was maintained in the evapotranspiration tank.

#### TRANSPLANTING, SURVIVAL, AND GROWTH OF WOODY PHREATOPHYTES

Transplanting of greasewood and rabbitbrush to the tanks was undertaken with some trepidation, for it was the first time transplanting on a large scale for experimental purpose had been attempted. Seedling plants were used for both species. Some consideration was given to transplanting mature plants, but it was feared that damage to their deep-root systems would be so great that many of the plants would not survive. During excavation for the tanks, greasewood roots were observed and photographed at depths of 7 and 8 feet; judging from the root size at these depths, the roots probably extended to a depth of at least 10 feet.

The seedling greasewood plants were obtained in the general vicinity of the tanks. In the transplanting procedure, the seedlings were dug from the ground with care taken to keep as much soil as possible around the roots, placed in a wheelbarrow, covered with wet burlap, and transported to the tank for planting. Each seedling was examined carefully before planting, and seedlings with obvious root damage were discarded. Prior to planting, the average spacing of the plants in the area was ascertained by random transects. Because some loss of the transplanted shrubs was anticipated, the seedling spacing was closer in the tanks than in the surrounding growth, for which the average spacing was 8–3½ feet. Eighty-five plants were planted in greasewood tank 1 and 105 in tank 2 in mid-April 1960. At the end of September, 71 plants were growing in tank 1 and 89 in tank 2, a survival rate of 84 and 85 percent, respectively, for the two tanks. Figure 9 shows the growth in greasewood tank 2, 5½ months after planting. Some additional transplanting was done in the spring of 1961 to fill the spaces where two or more adjacent plants had died.

Rabbitbrush plants were not available in the immediate vicinity of the test site; however, an extensive growth about one-half mile distant provided an ample supply of seedlings. The young plants were

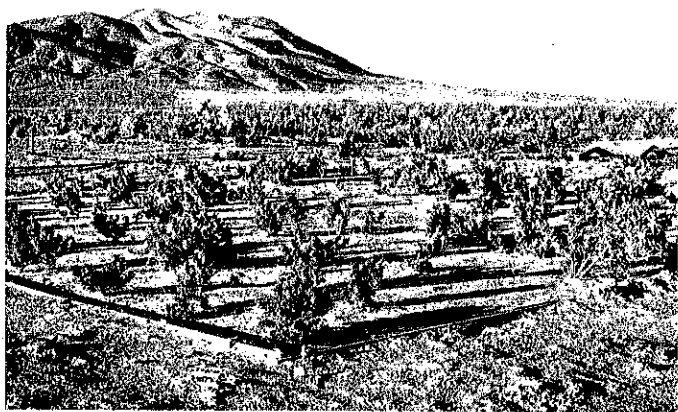


FIGURE 9.—Greasewood plants in tank 2 on September 30, 1960. Of 105 seedlings planted on April 13, 1960, 89 rooted and thrived.

easily dug from sandy loam with a minimum of damage to the roots. The seedlings were planted in irregular rows, and at a closer spacing than for the greasewood, to simulate observed field conditions. The plantings on April 10 and 11, 1962, were as follows: 75 plants in tank 1, 86 in tank 2, and 90 in tank 3. A count of the living plants on July 9, 1962, showed 63 surviving in tank 1, 75 in tank 2, and 86 in tank 3. An item of interest was the location of the dead plants. Plant mortality in each of the three tanks was greatest in the center of the tank and least along the edges. Replanting in the spring of 1963 did little to alter this pattern.

The willow tanks were planted on April 14, 1960, using cuttings from the thicket in which the willow tanks were located. The cuttings, about 10 inches long, were stuck into the wet soil surface of the tanks to a depth of about 6 inches at approximately 1-foot intervals. An inspection on September 30 showed that about 99 percent of the cuttings had taken root and were growing. The growth by October 1, as shown in figure 10, ranged in height from  $1\frac{1}{2}$  to  $3\frac{1}{2}$  feet and averaged about  $2\frac{1}{2}$  feet.

The wildrose tanks were also planted with cuttings from the surrounding area. The plantings on May 20 took root, thrived, and were well established by the end of the 1960 growing season. Survival rate was high, averaging about 95 percent.

#### OPERATION OF THE TANKS

With the exception of the year of planting, studies of evapotranspiration in the tanks were started each year on April 1 and ended on October 20. The emphasis following planting was on the establishment of a healthy and vigorous growth. The period April 1 to October 20 was selected because it spanned the dates of earliest and latest beginning and end of the growing season. Generally water could not be supplied to the tanks for

the entire period each season. Water systems were disrupted in some years near the beginning of the season and in other years near the end of the season when below freezing temperatures at night caused water lines and water meters to freeze and burst.

Samples of the soil and of the water in the tanks were collected once or twice a year, following the first full growing season, for chemical analysis. The analyses provided data on the concentration of salts in the soil and water, and warned of any salt buildup that could be detrimental to the plants.

Once the operating water level for the growing season was established and the float mechanism for controlling the water level adjusted, the day to day operation was fairly simple. At the start of the season, the reservoirs were filled to their operating capacity, indicated by a reference mark on a manometer tube attached to the side. The reservoirs supplying the greasewood and rabbitbrush tanks had a capacity of 350 gallons, and those for the willow, wildrose, and bare soil tanks 100 gallons. With the outlet valve of the reservoirs open, water delivered to the evapotranspiration tanks was controlled at the tanks by the float-valve mechanisms. The quantity of water supplied to the evapotranspiration tank in any period replaced water used by the plants. It is a measure of the draft from the ground-water reservoir.

The quantities of water used were determined by refilling the supply tanks to the reference marks at the end of each period with water measured through the water meter. It was not feasible to meter water directly into the evapotranspiration tanks because of the low demand-rate of flow. The rate varied from a trickle to about 1 gallon a minute during the course of a day. These rates were too low for proper actuation and operation of the meter.

The interval between refills varied, depending on the

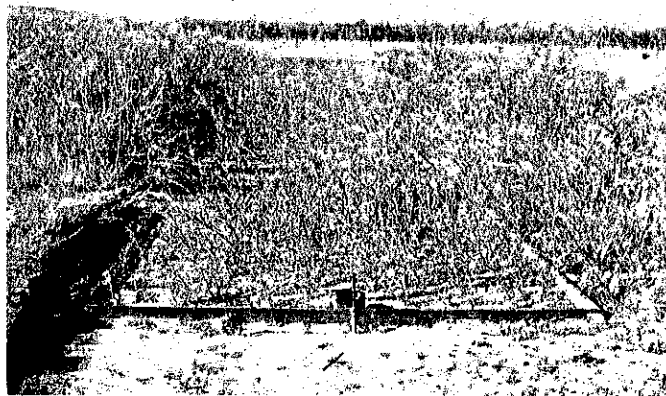


FIGURE 10.—Growth of plants in willow tanks on October 1, 1960, from cuttings planted on April 14, 1960. Average height,  $2\frac{1}{2}$  feet, density comparable to that in surrounding thicket.

date within the growing season. At the beginning and end of the season, when water use by plants was low, the reservoirs were refilled at weekly or 10-day intervals. During the height of the season, in July and August, it was not uncommon to fill them every day or every second day. All reservoirs, regardless of the need, were refilled on the first day of each month. In this way, the water use by months was obtained. Refilling was usually done in the morning, generally between 9 and 10 o'clock. At each filling, the operator compared the water use of the current period with that of the previous period, and thus was alert to any unusual condition. Some difficulty was experienced with sediment clogging the float-valve outlets, reducing and even stopping delivery of water to the evapotranspiration tanks. On a few occasions, the submergence of a float that developed a leak kept the float valve open and thereby allowed excess water to enter the tank. On other occasions, the horizontal-distribution system in the bottom of the greasewood tanks became partly clogged and restricted inflow. Unusual conditions such as these were quickly noted and easily corrected.

#### WATER LEVELS

With the exception of the interval following planting, while the plants were getting established, the water levels in the evapotranspiration tanks were controlled at predetermined depths below the surface of the tank. During and following planting of the seedlings or cuttings, the depth to water was maintained from 1 to 2 feet below the surface so that the soil at the root level might be kept moist. As the plants became established and the roots developed, the water level was allowed to decline slowly, until the approximate operating level was reached.

All the evapotranspiration tanks were operated for the first 3 of 4 years with a water level 5 feet below the surface of the tank. When adequate data for that depth had been obtained, the water level was raised or lowered, and water-use data was obtained for different depths to water. The operating water levels for the different species and the different tanks, for the period of study, are given in the following tabulation:

#### Operating water levels for the evapotranspiration tanks

Growing season	Tank	Depth to water level (ft)	Remarks
Greasewood			
1961.....	1, 2	5.0	Aug. 1 to Oct. 21.
1962-63.....	1, 2	5.0	
1964.....	1, 2	6.0	Apr. 1 to Aug. 4. Membrane accidentally perforated on Aug. 4.
1965.....	1	7.5	
1965.....	2	6.0	
1966.....	1	7.6	
1966.....	2	6.2	
1967.....	1, 2	7.8	
Willow			
1961.....	1, 2, 3	5.0	July 13 to Oct. 21.
1962-63-64.....	1, 2, 3	5.0	
1965.....	1	5.7	Tank 3 discontinued.
1965.....	2	3.5	
1966.....	1	5.8	
1966.....	2	4.2	
1967.....	1	5.4	
1967.....	2	4.1	
Rabbitbrush			
1963-64-65.....	1, 2, 3	5.0	
1966.....	1, 2, 3	5.3	
1967.....	1, 2, 3	6.2	
Wildrose			
1963-64.....	1, 2, 3	5.0	Tank 3 discontinued.
1965.....	1	5.0	
1965.....	2	4.2	
1966.....	1	5.9	
1966.....	2	4.2	
1967.....	1	6.1	
1967.....	2	4.4	
Bare-soil tank			
1962.....		4.0	
1963.....		2.2	
1964.....		1.9	
1965.....		2.3	
1966.....		4.0	

#### SOURCES OF WATER FOR EVAPOTRANSPIRATION

Evapotranspiration rates, as determined from the tank studies, are for the period of the growing season, April 1 to October 20. The data are indicative but may not be applicable to the full year, as precipitation was not measured during the nongrowing season. In other similar tank studies in the southwestern United States where the winters are mild, evapotranspiration rates are determined for the full year.

The water that made up the evapotranspiration discharge was supplied from three sources, namely, (1) rainfall, (2) water supplied to the tanks, and (3) soil moisture.

#### RAINFALL

As noted earlier, rainfall was measured by a standard 8-inch rain gage at the weather station. The catch of the rain gage was considered the water supplied by rain. During the period of study, rainfall ranged widely not only in amount for the growing season but also in the intensity and frequency of individual storm periods. Rainfall for storm periods ranged from a low of 0.01 inch in July and September 1966 to a high of 1.96 inches during a 4-day period in June 1964. During July 1962 and 1963 and October 1964 and 1966, there was no measurable rainfall.

Rainfall, in inches, from April 1 to October 20, is given in the following tabulation:

*Rainfall, in inches, from April 1962 to October 1967*

Year	Apr.	May	June	July	Aug.	Sept.	Oct.	Period
1962.....	0.23	0.35	0.25	0.00	0.13	0.05	0.35	1.36
1963.....	1.20	1.65	2.67	.00	.25	.25	.49	6.51
1964.....	.87	.97	2.10	.35	.08	.46	.00	4.83
1965.....	.81	.77	1.06	.34	.42	.09	.14	3.63
1966.....	.38	.33	.48	.01	.02	.42	.00	1.64
1967.....	.98	.21	1.51	.38	.19	.22	.06	3.52

#### WATER SUPPLIED TO THE TANKS

The water supplied to the evapotranspiration tanks was the largest of the three sources of water for evapotranspiration. This water represented the draft on the ground water by the plants. Draft on the ground water will vary from season to season depending on the rainfall, the climatic conditions, and the portion of the winter rainfall available to the plants. The quantities, expressed as acre-feet per acre, supplied to each tank during the growing seasons from 1962 thru 1967 are given in the following tabulation:

*Water, in acre-feet per acre, supplied to the evapotranspiration tanks during the growing seasons from 1962 to 1967*

Species	Tank	1962	1963	1964	1965	1966	1967
Greasewood.....	1	1.32	0.90	0.56	0.42	0.83	0.56
	2	.98	.88	.61	( <sup>1</sup> )	.98	.62
Rabbitbrush.....	1	1.39	1.10	.68	1.18	1.39	
	2	1.42	.98	.63	.85	.72	
	3	1.76	1.20	.75	1.16	.91	
Willow.....	1	1.90	2.89	1.76	1.48	2.30	1.55
	2	1.55	2.97	1.80	2.13	3.19	1.85
	3	1.60	3.82	1.87	( <sup>2</sup> )		
Wildrose.....	1		1.04	.86	.83	1.23	1.08
	2		.69	.89	1.26	1.75	1.46
	3		.68	.76	( <sup>3</sup> )		
Bare soil.....		.17	.30	.63	.23	.18	( <sup>3</sup> )

<sup>1</sup> Membrane perforated August 1965.

<sup>2</sup> Discontinued in 1966.

<sup>3</sup> Unmeasured water entered tank 1967.

NOTE.—1 foot of depth of water over the tanks is equivalent to: 6,733 gallons for greasewood 1; 6,695 gallons for greasewood 2; 2,992 gallons for rabbitbrush 1, 2, and 3; 748 gallons for willow 1, 2, and 3, wildrose 1, 2, and 3, and bare soil.

#### SOIL MOISTURE

The plants in the evapotranspiration tanks obtained part of their seasonal water supply from soil moisture in the unsaturated zone above the water table. The differences in the water content of the soils in the tanks at the beginning and end of the growing season provided a measure of the quantity of water obtained by the plants from this source.

Determinations of the volumes of water in the soils in the evapotranspiration tanks and of seasonal variations in the water content were started in 1962. Neutron-meter observations of soil moisture were made in access tubes installed in each of the tanks at the beginning, middle, and end of the growing season except in 1962 and 1963 when additional observations were made. The tubes were of sufficient length to permit sampling to nearly the full depth of the tanks, and the bottoms were sealed in order to permit observations at depths below the water levels in the tanks.

The quantities of water, in acre-feet per acre, obtained by the plants from soil moisture during the growing seasons 1962 through 1967, and the observed changes in water content of the soil in the bare-soil tank are shown in the following tabulation: These data represent net changes in water content for the full profiles sampled, although the principal depletions of soil moisture occurred in the unsaturated zone.

*Soil-moisture depletion, in acre-feet per acre, in evapotranspiration tanks at the Winnemucca test site during the growing season*

[Parentheses indicate gain in soil moisture, generally as result of adjustment of water level in tank after start of seasonal operation]

Species	Tank	1962	1963	1964	1965	1966	1967
Greasewood.....	1	0.37	0.44	0.26	0.42	0.24	0.43
	2	.38	.53	.39		.25	.64
Rabbitbrush.....	1	.09	.22	.19	.21	.65	.40
	2	.09	.22	.09	.14	.28	.37
	3	.10	.23	.12	.00	.36	.52
Willow.....	1	.34	.27	.10	.29	.28	.25
	2	.51	.28	.23	.15	.22	.24
	3	.38	.26	.26			
Wildrose.....	1	(.01)	.14	.10	.10	.19	.21
	2	.03	.21	.14	.18	.24	.16
	3	.15	.27	.20			
Bare soil.....		.14	.03	(.03)	(.01)	.04	.08

The water provided to the plants from soil moisture each season constituted a significant part of the seasonal supply for each species. This source supplied 27 percent of the total use in the greasewood tanks during the study period, 17 percent in the rabbitbrush, 10 percent in the wildrose, and 8 percent in the willow tanks. The contributions varied widely from year to year owing to differences in plant growth, water level, and the availability of soil moisture. The changes in water content in the bare-soil tank, however, were very small, and the water lost by evaporation was derived in approximately

equal shares from precipitation and water supplied to the tank.

Infiltration from winter precipitation was the principal source for replenishment of moisture in most of the soil above the capillary fringe. The water available to the plants from soil moisture varied annually as a result of variations in winter precipitation and opportunity for infiltration. The changes in soil-moisture volumes between the end of one growing season and the beginning of the next were a measure of the portion of the winter precipitation that was stored during the non-growing season. The total precipitation during this period actually was greater than the measured quantity, as part was lost by evaporation from the soil and plant surfaces, perhaps some by evapotranspiration, and some by sublimation of snow and ice.

A description of the instruments and procedure used in the measurement of soil moisture in the evapotranspiration tanks, illustrations of composite soil-moisture profiles in the tanks for the species studied, and some selected results are given in the section "Soil-moisture determinations" in this report.

The section also includes a brief discussion of seasonal soil-moisture changes in shallow flood-plain deposits as observed in the vicinity of the Winnemucca test site. These latter findings demonstrate (1) the characteristics of soil-moisture availability to phreatophytes growing on the flood plain and (2) the relative volumes of water stored in the unsaturated flood-plain sediments and carried over after wet seasons to the following season or discharged by evapotranspiration or by ground-water outflow in dry seasons. The volumes of water in storage in these sediments also may be indicative of the capacities available for inflow and storage of floodflows and the corresponding effects on streamflow downstream. Observations during a flood period in June 1962, for example, indicated the water content of the sediments to be more than 1 acre-foot per acre greater than in September 1961, which was near the end of a 3-year dry period. By October 1962, the water content had declined only about a half of this amount, with resultant carry-over of about one-half acre-foot per acre to the following season. The water content at the end of the following seasons, 1963-65, increased slightly, but by the end of the 1966 season, which was dry, the water content dropped to the September 1961 level. The large changes in storage in 1962, 1966, and 1967 thus would be representative of significant differences between the annual precipitation, streamflow, and water available to plants on the flood plain.

## COMPUTATIONS OF EVAPOTRANSPIRATION

Evapotranspiration was computed as the sum of the water supplied to the tank, precipitation during the growing season, and the difference in soil moisture at the beginning and end of the growing season. Because the water from the three sources was measured in different units, each was converted separately into equivalent depth of water in feet for the area of the tank; that is, acre-feet per acre. Water supplied to the tank during the season was considered to represent the draft on ground water under the conditions of growth in the tank.

Water that may have been added or withdrawn prior to the beginning of the growing season in order to establish the desired operating water level for the season was not included in the computations of evapotranspiration.

## PLANT GROWTH AND DEVELOPMENT

The growth and development of the plants were observed and recorded by photographs and measured by means of transects across the tanks. Photographs in color (35 mm transparencies) and in black and white were taken at 4-6-week intervals during the growing season. The color transparencies provided a chronological record of changes in the color of the foliage. Subtle changes in color, indicative of distress in the plants resulting from an unfavorable environment, could be detected by comparing the transparencies with transparencies taken at a prior time or with the actual growth in the tanks. For example, during the summer of 1962 there was a slow progressive change in the color of the foliage of the greasewood plants in both tanks from dark green to yellowish green, the result of a deleterious salt buildup in the soil.

After the plants had become well established, measurements of the vegetative growth were made, beginning with the second full growing season. From a series of measurements made in July, August, and September of 1963 and 1964, it was found that the foliage was at a maximum and that most of the plant growth for the season had occurred by about the first of August. When the early part of the growing season was warm, maximum plant development occurred in late July; when the season was cool, the maximum occurred in early August. Some variation in foliage development among the four species was observed also. Willows were the earliest to reach their peak in growth and foliage development, and rabbitbrush was the latest. In a given season the difference in time was not great, generally only 2 to 3 weeks.

## FOLIAGE VOLUME

Foliage volume, computed from measurements of the height and crown intercept of the plants, is the product of cover density (expressed in percent), vertical thickness of the foliage, and surface area of the tank. In general, the foliage of the four species extended from the crown of the plants to the surface of the tanks, and the height of the plants thus was equal to the thickness of foliage. The cover density and thickness of foliage were obtained by transects across the tanks. The number of transects for a tank depended on the size of the tank. Four transects having a total length of about 140 feet were measured across each greasewood tank—two on the diagonal and two at the midsections. Diagonal transects were used for the smaller rabbitbrush tanks in which the two transects measured totaled 57 feet, and the willow and wildrose tanks in which the two transects totaled 28.5 feet.

Cover density is considered synonymous with crown cover and is defined by Horton, Robinson, and McDonald (1964, p. 9, 36) as "the amount of ground covered or shaded by the vegetation foliage." Cover density is measured by vertically projecting the transect intercept of the crown of the plant onto a tape stretched horizontally across the tank and by noting the length of the intercept. (See fig. 11.) The summation of the vertical projections of the crown intercepts, expressed in percentage of the transect length, is the measure of the crown cover for the transect.

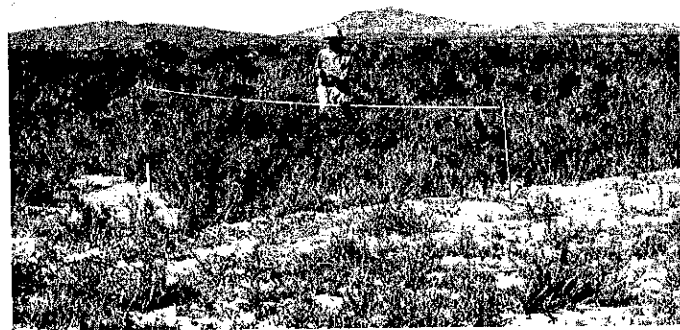


FIGURE 11.—Scientist measuring cover density and plant height on a transect across greasewood tank 2.

The results of one diagonal transect across greasewood tank 2, the computations for obtaining the average weighted height or thickness of foliage, and the cover density together with the method for computing

the volume of foliage are shown in the following example:

*Transect across greasewood tank 2, southeast to northwest corners, Aug. 4, 1968*

Interval (ft)	Vegetation			Height times intercept (sq ft)
	Species <sup>1</sup>	Height (ft)	Intercept (ft)	
0.0 to 1.0	B	-----	-----	-----
1.0 to 2.0	G	1.1	1.0	1.10
2.0 to 5.5	B	-----	-----	-----
5.5 to 8.2	G	1.1	2.7	2.97
8.2 to 9.5	B	-----	-----	-----
9.5 to 12.2	G	2.0	2.7	5.40
12.2 to 16.8	G	3.2	4.6	14.72
16.8 to 21.7	B	-----	-----	-----
21.7 to 26.0	G	3.0	4.3	12.90
26.0 to 31.0	G	2.5	5.0	12.50
31.0 to 35.9	B	-----	-----	-----
35.9 to 38.0	G	1.3	2.1	2.73
38.0 to 38.5	G	(Dead plant)		
38.5 to 39.0	B	-----	-----	-----
39.0 to 41.1	G	1.7	2.1	3.57
41.1 to 41.9	B	-----	-----	-----
41.9 to 42.9	G	.8	1.0	.80
Total	-----	-----	25.5	56.69

<sup>1</sup> B, bare; G, greasewood.

NOTE.—Length of transect 42.9 ft. Other computations are as follows:

Computations for transect:

$$\text{Average weighted height} = \frac{56.69}{25.5} = 2.22 \text{ ft.}$$

$$\text{Cover density} = \frac{25.5 \times 100}{42.9} = 59.4 \text{ percent.}$$

Computations for tank, based on four transects:

$$\text{Average weighted height} = 2.05 \text{ ft.}$$

$$\text{Average cover density} = 49.55 \text{ percent.}$$

$$\text{Area of tank} = 900 \text{ sq ft.}$$

$$\text{Foliage volume: } 2.05 \times 900 \times 0.4955 = 915 \text{ cu ft.}$$

Variation occurred in the height of the plants as well as in the height of different parts of individual plants, for example, between the center and perimeter of the crown. These variations necessitated refinement of the method of height measurement so that an average plant height for each transect could be determined. For individual plants, the results of several measurements of the height of the crown along the transect were averaged. For plants of different heights, the transects were segmented into intercepts across a plant or group of plants of approximately equal height.

An example of the variation in height is afforded by the willow tanks. During the winter of 1963–64, rabbits—present despite the ostensibly rabbit-proof fence—gnawed the bark of the stems girdling and killing some plants and severely damaging others. Regrowth from the crown was rapid, and by August 1964 the new growth was about one half as tall as the undamaged growth. This combination of new and old growth made it quite difficult to obtain a measure of the average

height of the plants. In computing the foliage volume, a weighted average plant height was used. The weighted average plant height for each tank was obtained by dividing the sum of the products of crown intercept and height of the plant for the transects by the total length of the transects.

The results of the transect measurements for each season for the various tanks and the foliage volume computed from them, together with the depth to the operating water levels for that season, are given in table 1.

TABLE 1.—Growth and development of woody phreatophytes grown in evapotranspiration tanks at the Winnemucca test site

Year	Cover density (percent)	Plant height (ft)	Foliage volume (cu ft)	Depth to water level below surface of tank (ft)	Remarks
<b>Greasewood tanks</b>					
1961					
Sept. 14.....	25.5	1.21	278	5.0	Tank 1.
	29.5	1.35	358	5.0	Tank 2.
1962					
June 13.....	49.6	1.37	610	5.0	Tank 1.
Aug. 8.....	39.1	1.43	503	5.0	Tank 2.
	55.4	1.58	784	5.0	Tank 1.
	38.9	1.43	601	5.0	Tank 2.
1963					
July 17.....	61.9	1.97	1,091	5.0	Tank 1.
	47.9	1.91	823	5.0	Tank 2.
Sept. 6.....	56.4	2.01	1,015	5.0	Tank 1.
	40.4	1.75	730	5.0	Tank 2.
1964					
Aug. 4.....	62.4	2.14	1,195	5.0	Tank 1.
	47.3	1.97	839	5.0	Tank 2.
1965					
Aug. 3.....	59.2	2.19	1,181	7.5	Tank 1.
	50.4	2.06	935	( <sup>1</sup> )	Tank 2.
1966					
Aug. 4.....	51.7	2.26	1,046	7.6	Tank 1.
	49.8	2.05	915	6.2	Tank 2.
1967					
July 26.....	52.1	2.24	1,045	7.8	Tank 1.
	49.3	2.12	940	7.8	Tank 2.
<b>Rabbitbrush tanks</b>					
1963					
July 17, 18.....	37.8	1.29	197	5.0	Average of 3 tanks.
Sept. 6.....	46.2	1.45	272	5.0	Do.
1964					
Aug. 5.....	51.0	1.64	335	5.0	Do.
1965					
Aug. 4, 6.....	54.1	1.90	411	5.0	Do.
1966					
Aug. 4, 6.....	56.0	2.05	460	5.3	Do.
1967					
July 26.....	58.8	2.35	553	6.2	Do.
<b>Willow tanks</b>					
1961					
Sept. 14.....	81.6	3.26	266	5.0	Tank 1.
	77.7	2.82	219	5.0	Tank 2.
	78.8	2.94	232	5.0	Average of 3 tanks.
1962					
June 14.....	84.8	3.21	272	5.0	Tank 1.
Aug. 30.....	96.8	4.24	411	5.0	Do.
	86.9	4.38	351	5.0	Tank 2.
	92.8	4.32	400	5.0	Average of 3 tanks.
1963					
Sept. 6.....	88.3	4.40	399	5.0	Tank 1.
	87.2	5.06	441	5.0	Tank 2.
	89.5	4.68	419	5.0	Average of 3 tanks.
1964					
Aug. 4.....	78.9	4.33	342	5.0	Tank 1.
	90.5	4.97	450	5.0	Tank 2.
	87.7	4.51	396	5.0	Average of 3 tanks.

See footnotes at end of table.

TABLE 1.—Growth and development of woody phreatophytes grown in evapotranspiration tanks at the Winnemucca test site—Con.

Year	Cover density (percent)	Plant height (ft)	Foliage volume (cu ft)	Depth to water level below surface of tank (ft)	Remarks
<b>Willow tanks—Continued</b>					
1965					
Aug. 6.....	83.7	4.34	363	5.7	Tank 1.
	94.3	5.00	528	3.5	Tank 2.
				( <sup>2</sup> )	
1966					
Aug. 5.....	58.1	3.74	217	5.8	Tank 1.
	74.8	5.23	391	4.2	Tank 2.
1967					
July 27.....	56.7	3.74	212	5.4	Tank 1.
	75.2	5.72	430	4.1	Tank 2.
<b>Wildrose tanks</b>					
1962					
Aug. 8.....	63.5	1.73	110	5.0	Tank 1.
	24.1	1.20	29	5.0	Tank 2.
	50.5	1.64	78	5.0	Average of 3 tanks.
1963					
Sept. 4.....	77.7	2.11	164	5.0	Tank 1.
	80.6	1.67	101	5.0	Tank 2.
	72.2	2.10	154	5.0	Average of 3 tanks.
1964					
Aug. 4.....	79.8	2.34	187	5.0	Tank 1.
	73.6	2.57	189	5.0	Tank 2.
	80.6	2.64	214	5.0	Average of 3 tanks.
1965					
Aug. 4.....	75.5	2.13	161	5.0	Tank 1.
	72.7	2.05	193	4.2	Tank 2.
				( <sup>3</sup> )	
1966					
Aug. 5.....	64.0	1.73	111	5.9	Tank 1.
	60.0	2.42	145	4.2	Tank 2.
1967					
July 27.....	76.6	1.77	136	6.1	Tank 1.
	79.0	2.81	205	4.4	Tank 2.

<sup>1</sup> Variable water level in tank 2, resulting from leak in plastic membrane.

<sup>2</sup> Plants damaged by rabbits gnawing bark; some stems died.

<sup>3</sup> Tank 3 discontinued on account of leaks in membrane.

The variations in growth and development of the plants are reflected in the changes in foliage volumes from one season to the next, as shown in figure 12. Only those tanks are shown for which the record of foliage volume and operating water level are continuous for the period of record. Curves for willow tank 3 and wildrose tank 3 are not shown, as they were discontinued in 1965. For the most part, the foliage volumes showed a rather uniform increase during the early part of the study when the plants were becoming established and the operating water levels in all the tanks were maintained at a depth of 5 feet.

In order to observe the effects of differences in depth to water on the growth rates after the plants had become established, the operating water levels were changed from the 5-foot depth. The relation of foliage volume to those changes in water level is shown in the curves of the foliage volumes of greasewood, willow, and wildrose. For the rabbitbrush tanks, in which the 5-foot water level was maintained after the plants had become established, the foliage volume increased at nearly the same rate over the 3-year period 1963 through 1965; practically the same rate continued in 1966 and

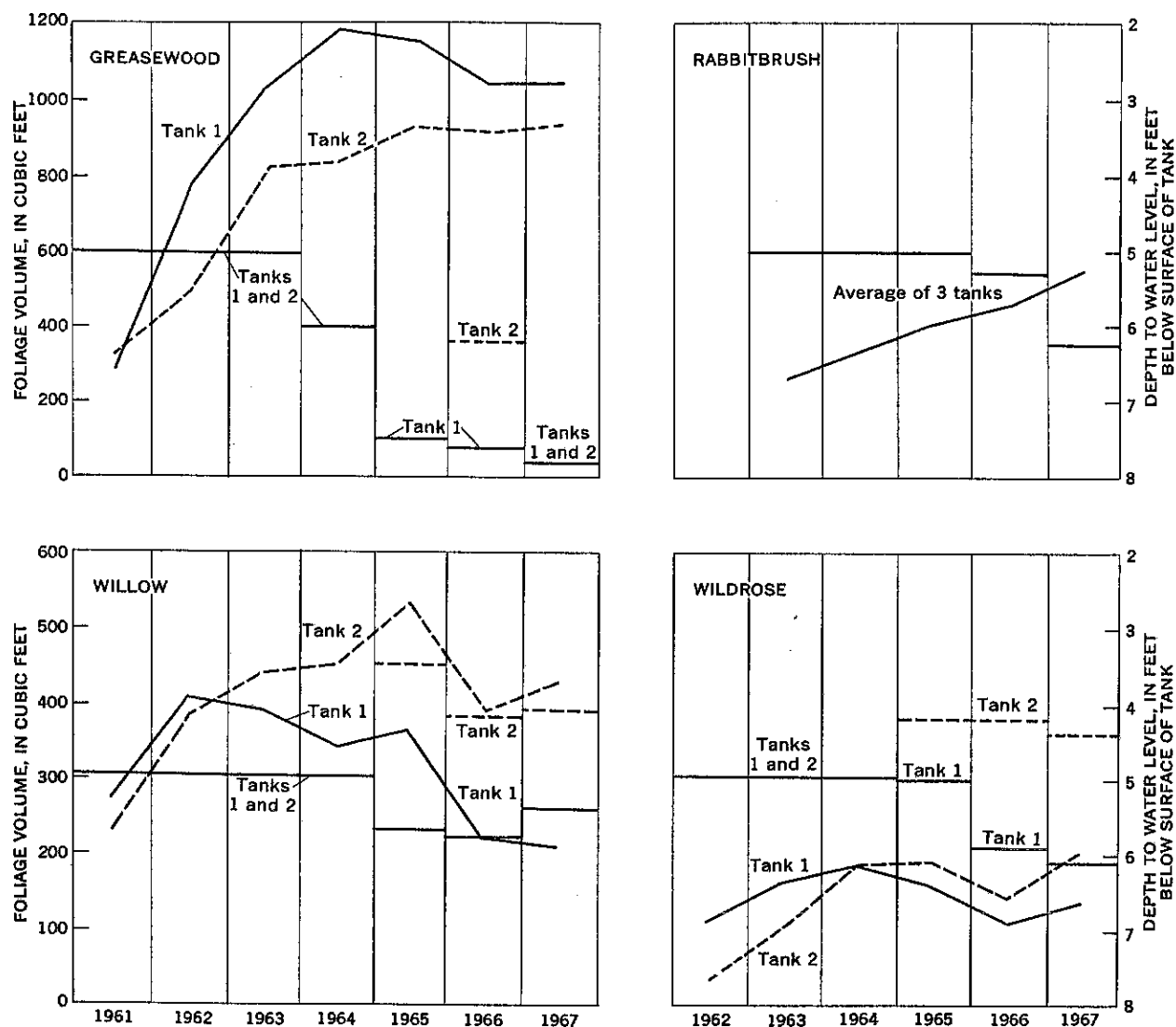


FIGURE 12.—Seasonal foliage volumes and operating water levels for the four species of phreatophytes grown in evapotranspiration tanks.

1967, when the water level was lowered from 5.0 feet to 5.3 feet in 1966 and from 5.3 to 6.2 feet in 1967.

There was a moderate to small increase in foliage volumes for the greasewood tanks in 1964 when the water level was lowered from 5 feet to 6 feet below the surface of the tank; however, the amount of increase was less than with the 5-foot water level from 1962 to 1963. The record for tank 2 was interrupted during the 1965 season because a leak in early August resulted in a variable water level for the remainder of the season. When the leak was repaired in the spring of 1966, the tank again became operational. The foliage volume (as shown) was measured in 1965, but the water level is not shown because of its variation. Foliage volume for tank 1 decreased in 1965 and 1966, when the water level in tank 1 was lowered from 6.0 to 7.5 feet, and in tank 2

in 1966, when the level was lowered to 6.2 feet, following repair of the ruptured membrane. In 1967, however, with the water level in both tanks at 7.8 feet, there was no further decrease in the foliage volume of tank 1, and there was a small increase in tank 2. It is inferred from this fact that the plants had become established and adjusted to the deeper water levels. If such is the case, it points up an important principle of phreatophyte growth; namely, that a lowered water level affects the plant only temporarily pending readjustment of the root system to the new environment, provided the lowered water level is not beyond the reach of the roots.

The effect of the damage to the willow plants by rabbits during the winter of 1963-64 resulted in a decrease in the foliage volume for tank 1 and a reduction in the rate of increase in foliage volume in tank 2

during the 1964 growing season. The foliage volume in tank 1 increased during the 1965 season despite a water level lower than that in 1964. The increase in foliage volume for willow 2 was much greater in 1965 than in 1964. Part of the increase was attributable to the higher water level, raised from a 5-foot depth to a 3.5-foot depth, and part to a continued recovery from the damage by rabbits.

On the basis of the differences in the increase of foliage volume in the two willow tanks having different water levels, it is inferred that the plants did not recover completely in 1965 from the damage in the winter of 1963-64. During the second growing season, the plants evidently were still recovering from the damage. The decrease in foliage volume in tank 2 in the 1966 growing season is believed to reflect the effect of the greater depth to water level in 1966 when the water level was lowered 0.7 foot from 3.5 to 4.2 feet below the surface of the tank. The cause for the sharp decrease in foliage volume in tank 1 in 1966 is uncertain. Several plants died in 1966, and this is reflected in a decrease in cover density from 83.7 percent in 1965 to 58.1 percent and 37 percent in 1966. The cause of death was not apparent. There was only minor damage by rabbits and none by insects. In 1967 the water level was raised 0.4 foot in tank 1, from 5.8 feet to 5.4 feet below the surface of the tank, while in tank 2 the raise was only 0.1 foot from 4.2 to 4.1 feet. The foliage volume of tank 1 was almost unchanged from 1966, but in tank 2 there was a substantial increase. The halt in the downward trend in tank 1 and the increase in tank 2 are believed due in part to the higher water level and in part to the adjustment of the roots to the changed water environment as described for the greasewood tanks.

The plants in the wildrose tanks had in general a similar pattern in that large foliage volumes were produced when the water levels were shallow, and small volumes when the water levels were deep, except in 1965. In that year, with no change in water level, the foliage volume in tank 1 decreased about 14 percent. The reduction resulted from the death of stems of several plants in July.

Many variables affect plant growth and development such as climate, soils, salts in the soil, and water supply. However, none of these are responsible for the change in foliage volume of the tanks from year to year, as conditions were the same for each pair of tanks for each species. The differences in the paired tanks, shown in figure 12, can be due only to changes in the depth to water level during the growing season.

In order to have some basis for comparing greasewood growth in the tanks to growth in the field outside the tanks, several 100-foot transects were measured in the field. The transects, measured during the 1964, 1965, and

1966 growing seasons, sampled three localities having different growth conditions. The first locality was within the test-site enclosure near the north side; there the growth had not been disturbed by livestock grazing since the site was fenced in 1960. Although greasewood is not very palatable, cattle will browse on it at certain times of the year when hungry. At the same time, the plants may be damaged through trampling or by breaking of plant stems.

The second locality was outside the test-site enclosure and about 30 feet away from the first locality. There browse conditions were the same as those within the enclosure at the time it was fenced. This locality is in a pasture that is grazed moderately during the winter months.

The third locality, also outside the test site, was in a pasture that was heavily grazed and had frequently held small herds of cattle for periods of as much as 1 month. Damage to the plants from grazing and trampling was quite apparent. The results of the transect measurements, together with comparative data on average foliage volume of the two greasewood tanks, are shown in table 2.

TABLE 2.—Comparative data on greasewood growth in the field under different growth conditions and the average in the two evapotranspiration tanks

Year	Plant height (ft)	Cover density (percent)	Foliage volume (cu-ft per acre)
<b>Inside Winnemucca test-site enclosure</b>			
1964.....	2. 37	51. 3	52, 960
1965.....	2. 39	57. 3	59, 650
1966.....	2. 30	57. 8	57, 910
<b>Outside test-site enclosure (grazed moderately)</b>			
1964.....	2. 35	41. 3	42, 280
<b>Outside test site (grazed heavily)</b>			
1964.....	2. 08	28. 0	25, 370
1965.....	2. 04	33. 1	29, 410
1966.....	2. 04	36. 8	32, 700
<b>Average of two evapotranspiration tanks</b>			
1964.....	2. 06	54. 8	49, 170
1965.....	2. 12	54. 8	50, 620
1966.....	2. 16	50. 6	47, 590

Comparisons of plant growth on the basis of foliage volumes show that the undisturbed growth in the enclosure is about 15 percent greater than the average of the growth in the two tanks. This difference is not surprising in view of the fact that these plants were well established at the time the tanks were planted and have

been able to grow undisturbed since that time. The growth outside the enclosure, in the moderately grazed pasture, was about 10 percent less than the average of the two tanks. The difference in growth between the two localities, for which the plant growth was about the same in 1960, show that there was a substantial improvement in growth when the plants were protected from livestock grazing.

The effect of heavy grazing is reflected in the foliage volume of the transects in the heavily grazed pasture. Plant growth there was less than half that in the enclosure, about 40 percent of that in the moderately grazed pasture, and about 65 percent of that in the tanks.

These data indicate that man's activities in the management of livestock operations adversely affect greasewood growth. Other woody phreatophytes may be affected to a greater extent, as the palatability of some, such as willow, is higher than that of greasewood.

### PROBLEMS

In the planning of the evapotranspiration studies, some problems were anticipated in the operation of the tanks, in transplanting, and in establishing growths representative of those outside the tanks. Some problems arose as the result of nature's handiwork, whereas others resulted from the disturbance of nature's balance. An important objective of the project construction and development was the maintenance of the natural environment insofar as possible. In the tank construction, disturbance of the soils could not be avoided, and the soils were mixed to some extent and could not be replaced in the same layered sequence in which they occurred naturally.

The problems caused by nature included damage by insect infestation during the growing season and by rabbits during the winter months; they were not related to construction or operation of the tanks. Insect infestation was not restricted to the plants grown in the tanks but was widespread over the countryside. That condition recurs at intervals of several years. Damage by rabbits gnawing the bark of willow plants may be local or widespread depending on the severity of the winter and the scarcity of food available to the rabbit population.

The accumulation of deleterious salts in the root zone in several of the tanks was one of the problems resulting from the disturbance of nature's balance.

### DAMAGE BY WEBBING INSECTS

In early July 1960, a webbing insect spun webs and laid eggs on the greasewood plants in the tanks and on about 90 percent of the area of greasewood growth

in the Humboldt River valley, including the Winnemucca reach. The insect was identified as belonging to the family Pyrolidae, genus *Eumysia* sp. Infestations of the insect appear periodically throughout greasewood areas in Nevada and Idaho, and doubtless other western States. However, their only appearance during the period of study was in July 1960. *Eumysia* sp. was the night-flying insect that was discovered in 1950 by George Zappettini, State Forester for Nevada, and reported on in his dissertation for a master's degree at the University of Idaho. The larvae has a snout mouth, is from 10 to 16 millimeters long, is 3 millimeters in diameter, and has a voracious appetite. The adult has a wing span of about 23 millimeters and a body length of about 10 millimeters.

Webbing was confined almost entirely to greasewood and associated species such as rabbitbrush, shadscale, and occasionally a sagebrush plant. No webbing from this insect was observed in willow growth. The webs had a white or silver luster and were so numerous that in some areas when the sun was low on the horizon, as in early morning or late afternoon, they gave a soft silver sheen to vast areas of greasewood growth.

Damage due to the larvae feeding on the leaves was extensive; many of the leaves on the plants were shriveled and brown and presented a dead appearance. Serious damage to the greasewood plants in the tanks was avoided by spraying with the insecticide DDT on July 16. The plants in the tanks were only about 3 months old, and it was evident that unless the ravages by the insects were checked, the plants would be severely damaged and perhaps die. Although damage was extensive, the plants recovered rapidly following the spraying; by early August the plants presented a healthy green appearance and extensive new growth was apparent.

A different webbing insect, the so-called "tent caterpillar", spun webs, laid eggs, and produced larvae that damaged the willow plants. This insect, although also widespread, did not blanket the willow growth, but occurred randomly in groups or clusters. With the exception of the 1966 growing seasons, webs of the insect were found on one or more of the plants in the willow tanks beginning with the 1962 season. Serious damage again was avoided by spraying with DDT.

It could be argued that preventive measures should not be taken to guard against damage by insects, that they are a part of nature's checks and balances, and hence that the studies of evapotranspiration that use such measures do not simulate natural conditions. However, the newly transplanted greasewood shrubs were in grave danger of high mortality, and unchecked damage would have delayed the studies a full year.

Furthermore, the occurrence of the infestations at intervals of several years, rather than yearly, reduces their impact on the average annual evapotranspiration loss. As the tent caterpillar does not damage the willow growth everywhere, but only in spots, evapotranspiration losses from undamaged plants would be a closer representation than that from damaged plants.

#### DAMAGE BY RABBITS

The fence enclosing the test site was constructed to be rabbit proof, but rabbits did manage to enter. The rabbits probably came through the gate at times when it was open and workmen were in a remote part of the site. During the severe winter of 1963-64, rabbits damaged the willow plants in the tanks so badly that a number of the stems died. The rabbits gnawed the bark of the stems just above the surface of the tank and those that died were girdled or nearly so. Although vigorous regrowth occurred from the root crown during the 1964 growing season, a comparison of foliage volumes of the 1963 and 1964 seasons indicated that it was not enough to compensate for the loss of foliage from the dead stems. Damage to the plants by rabbits was noted also during the winters of 1964-65 and 1965-66, but it was not extensive and only a few stems died.

During the 1963-64 winter, there was damage also to the willows growing in the site outside the tanks, but it did not appear to be as severe as that in the tanks. Possibly the bark from the younger trees in the tanks was more palatable than that from the older trees.

In an effort to prevent or at least reduce further damage, a program to remove the rabbits from the test site was begun in the fall of 1964. Using a humane trap, in which the rabbits were captured alive, several rabbits were caught and then released outside the fenced site. The trapping program is believed responsible for the lesser damage in the following years.

#### SALT CONTENT OF THE SOILS

The soils of the terrace deposits, used in the greasewood and rabbitbrush tanks, were suspected to have an appreciable content of alkaline salts. However, because there was a luxuriant growth of greasewood on these soils, no difficulty was expected in growing greasewood plants in tanks containing the same soil, particularly as greasewood is known to have a high tolerance for alkaline salts.

The soils of the flood-plain deposits, used in the willow and wildrose tanks, were considered to have a low salt content. These deposits are subject to repeated leaching by overflow of the Humboldt River during spring runoff. The flood plain supported a dense and

luxuriant growth of willow, wildrose, and meadow grasses.

The higher salt content of the terrace deposits was confirmed by the appearance of an incrustation of salts on the surface of the greasewood and rabbitbrush tanks as the result of maintaining a high water level while the plants were becoming established, whereas there was no incrustation on the willow and wildrose tanks. A water-soluble portion of the incrustation samples collected in August 1960 was made by treating 1.015 grams of the oven-dried sample with a liter of water. The sample gave the following concentration in the extract:

	mg/l		mg/l
Ca	2.4	pH	10.1
Mg	.7	CO <sub>3</sub>	93
Na	115	SO <sub>4</sub>	60
Dissolved solids	350	Cl	28

In April 1962, samples of water from the saturated material below the water level were collected, for chemical analysis, from all but rabbitbrush tanks 1 and 3 and the bare-soil tank. The samples were obtained by withdrawing water from the water-distribution system of the tank by pumping. In order to have a representative sample from the 10- by 10-foot tank, at least 50 gallons was pumped to waste before sampling; greater volumes were pumped from the larger tanks. A sample of water was also collected from the well supplying water for the evapotranspiration tanks. Later, in August 1962, additional samples of water were collected from greasewood tank 2. The results of the chemical analyses, given in table 3, show clearly that the mineral content of the soils of the terrace deposits is considerably greater than that of the flood-plain deposits.

#### BORON TOXICITY

A wholly unexpected and serious effect on the growth of, and water use by, the greasewood plants occurred during the 1962 growing season. The first signs of distress, noticed in July 1962, were tip burn of the leaves and a change in color of the foliage. The color change from a normal dark green to a yellowish green became more pronounced as the season advanced. In addition to those symptoms of distress, there was progressive defoliation during August and September, and by early October some plants had lost more than half their leaves. Chemical analysis of leaf samples and of the soil in the tanks indicated that the difficulty was probably due to toxic concentrations of boron in the root zone.

The first indication that boron was responsible for the difficulty was the chemical analysis of a second sample of the incrustation on the soil surface of greasewood tank 1 collected in the fall of 1962. The results of the second analysis were startling, for it showed a boron

TABLE 3.—Chemical analyses of water from the saturated soil in the evapotranspiration tanks of the Winnemucca test site  
[Constituents given in milligrams per liter]

Date collected 1962	Gallons pumped before collecting sample	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Lithium (Li)	Bicarbonate (HCO <sub>3</sub> )	Carbonate (CO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Phosphate (PO <sub>4</sub> )	Boron (B)	Dissolved solids	Specific conductance (micromhos at 25°C)	pH
Project supply well															
Apr. 12.....	1,000+	48	14	103	11	0.12	320	0	78	51	0.16	0.44	507	785	7.81
Greasewood tank 1 <sup>1</sup>															
Apr. 9.....	100	153	43	1,260	31	0.29	2,750	0	518	384	5.5	13	3,800	5,190	8.14
9.....	770	79	23	1,030	25	.24	2,020	50	388	312	6.4	9.2	2,970	4,190	8.42
11.....	1,200	56	19	942	23	.21	1,840	39	326	274	7.0	8.8	2,650	3,800	8.40
Greasewood tank 2 <sup>1</sup>															
Apr. 7.....	500	99	30	768	31	0.19	1,690	0	338	262	6.7	7.1	2,420	3,460	8.19
Aug. 8.....	50	51	15	119	12	.....	360	0	88	57	.....	.47	.....	877	7.65
8.....	960	56	15	298	18	.....	700	0	156	106	.....	2.1	.....	1,600	8.13
9.....	1,470	53	15	350	19	.....	798	0	171	116	.....	3.3	.....	1,780	7.80
9.....	2,430	51	14	433	25	.....	959	0	176	130	.....	4.8	.....	2,060	7.70
9.....	2,650	51	14	449	23	.....	1,020	0	179	133	.....	4.5	.....	2,160	8.13
Rabbitbrush tank 2 <sup>1</sup>															
Apr. 12.....	100	197	55	768	29	0.24	1,280	0	672	492	0.57	2.1	2,910	4,170	7.95
Willow tank 1 <sup>2</sup>															
Apr. 6.....	50	107	27	143	13	0.09	668	0	73	59	0.09	0.47	799	1,220	7.82
Willow tank 2 <sup>2</sup>															
Apr. 7.....	50	115	31	148	13	0.09	632	0	73	97	0.05	0.40	836	1,320	7.42
Willow tank 3 <sup>2</sup>															
Apr. 12.....	50	117	34	140	13	0.09	668	0	73	89	0.10	0.43	850	1,340	7.56
Wildrose tank 1 <sup>2</sup>															
Apr. 8.....	50	79	46	162	13	0.14	749	0	53	61	0.02	0.51	835	1,310	7.60
Wildrose tank 2 <sup>2</sup>															
Apr. 8.....	50	99	36	183	14	0.13	816	0	49	67	0.05	0.61	887	1,380	7.87
Wildrose tank 3 <sup>2</sup>															
Apr. 8.....	50	120	49	140	11	0.10	792	0	57	30	0.03	0.38	896	1,410	7.44

<sup>1</sup> Terrace soil.<sup>2</sup> Flood-plain soil.

content of 416 milligrams per kilogram. To assess more exactly the amount of boron in the plant and in the soil, samples of leaves and of soil were collected in October 1962. The soil was sampled at 1-foot intervals to a depth of 8 feet in greasewood tank 1 and to 6 feet in tank 2 and to a depth of 4 feet in rabbitbrush tank 1. Samples were collected with a 3-inch earth auger. In augering for the samples in greasewood tank 2, a considerable quantity of root material was encountered between depths of 1 and 6 feet. The small roots and rootlets were carefully separated from the several soil samples and preserved for separate analysis of their boron content. Samples of the leaves shed were collected from both tanks and from plants growing outside the tanks, and samples of green leaves were plucked from plants growing in the two tanks.

The results of the analyses for boron content of air

dried portions of the leaf and root samples are given below:

[Leaves were collected on Oct. 18, 1962]

Greasewood tank 1		mg/kg
Shed leaves from six plants.....	120	
Green leaves, from the tips of branches.....	233	
Greasewood tank 2		
Shed leaves from two plants.....	125	
Green leaves from tips of branches.....	196	
Root material between the depth of 1-6 feet.....	54	
Greasewood plants growing outside of tanks		
Shed leaves from several plants.....	107	

The boron content of the shed leaves was about 20 percent higher for the plants in the tanks than for those on the outside, and the green leaves had nearly twice the content of boron that the shed leaves had. A

sample of green leaves was collected from plants growing outside the tanks, but unfortunately it was lost.

The soil samples were analyzed for their water soluble boron content by the Nevada Soil Testing Laboratory at the University of Nevada.<sup>1</sup> The greatest concentration in both greasewood tanks occurred between the depths of 3 and 4 feet, as shown in figure 13. In the graphs of figure 13, the boron content is plotted as the midpoint of the sample interval, 0.5, 1.5 feet, and so forth. The four samples from the rabbitbrush tank all had the same boron content, 5 mg/kg.

#### SOURCE AND ACCUMULATION OF BORON IN THE TOP SOIL

The terrace deposits are rich in boron, as was established by the chemical analysis of soil samples. The mineral form of occurrence is not known, but the results of soil analysis indicate that some of the boron is readily soluble in water and that a larger amount is in a relatively insoluble or only slightly soluble form. Boron in the water soluble form is presumed to be readily available to the plants and was given the most attention.

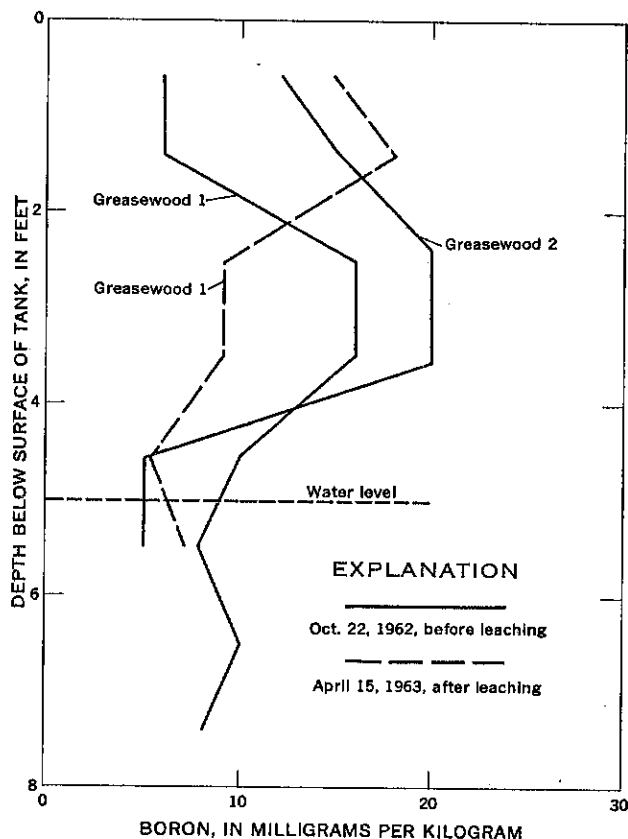


FIGURE 13.—Soluble boron content of the soil in greasewood tanks 1 and 2 before leaching and in tank 1 after leaching.

<sup>1</sup> In addition to boron, the sample was found to have a lithium content of 20 mg/kg.

In order to obtain information about the total concentration of boron in the deposits, four soil samples were analyzed. The samples were collected from greasewood tank 1 with a Veihmeyer soil-sampling tube. The sampling on October 23, 1963, was from the surface to a depth of 5.5 feet, at 1/2-foot intervals. Determinations were made of the soluble boron in all the samples and of total boron in four samples at depths from 0.5-2.5 feet. Total and soluble boron content of the four samples are given in the following tabulation:

Depth interval (ft)	Total boron (mg/kg)	Water soluble boron (mg/kg)
0.5 to 1.0	700	11.7
1.0 to 1.5	875	18.1
1.5 to 2.0	1,140	7.34
2.0 to 2.5	280	11.7

The soluble boron content probably would have been higher had not the soil in the tank been leached the previous October. The analyses indicated that a large supply of boron is stored in the soil in some form not readily soluble; however, this material may be slowly decomposed by chemical reactions with water and solutes in the tank, and accumulations of the decomposition products in the tanks could lead to toxic quantities of soluble boron. The analyses for insoluble boron content illustrate the magnitude of the total boron supply in the tanks. The depths at which the samples were collected have no relation to natural soil profiles, as the soil in the tank had been disturbed.

In addition to the sampling in the tank, three sets of samples of the soil profile and two sets of surface-soil samples were collected for soluble boron determination from the undisturbed soil outside the tanks. The sampling points were in the midst of a thicket of about 15 greasewood plants. The starting point for the lines of lateral samples was the central stem of one of the large plants. Figure 14 shows the location of the sampling points, the lateral lines of sampling, and the surrounding greasewood growth. The dates, depths, and sampling interval are given in the following tabulation:

Vertical sampling			
Sampling point	Date	Depth sampled (ft)	Sampling interval (ft)
A	Oct. 22, 1962	0-9	1.0
B	Apr. 9, 1963	0-1.5	0.25
C	Oct. 23, 1963	0-5.5	0.5
Lateral sampling			
Sampling line	Date	Distance from central stem of greasewood plant (ft)	Sampling interval (ft)
D-E	Apr. 9, 1963	1-8	1
D-F	Oct. 25, 1963	0-8	1

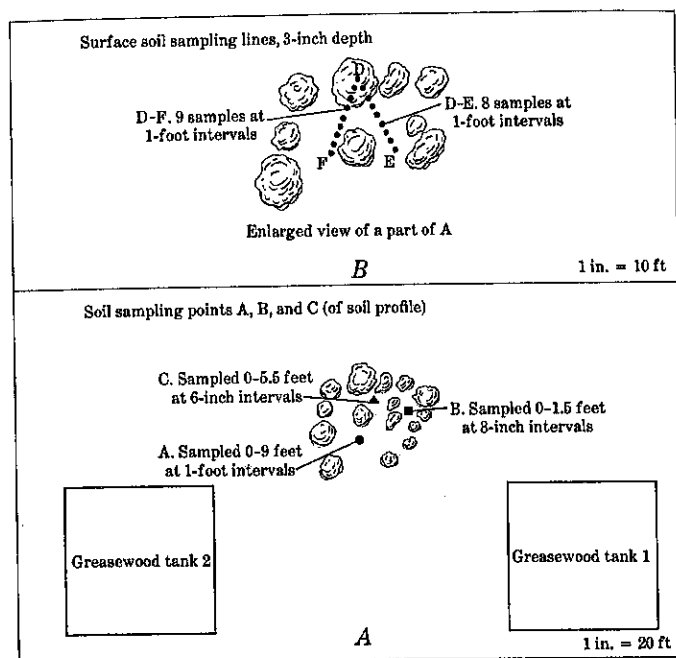


FIGURE 14.—Location of points and lines used in sampling undisturbed soil, in relation to clumps of greasewood.

The nine samples collected from sampling point A by means of a soil auger were analyzed by the Nevada Soil Testing Laboratory at the University of Nevada. All the other samples were analyzed by the Water Resources Division Laboratory of the Geological Survey at Menlo Park, Calif. The samples collected from point B were taken from the side of a 1.5-foot dug pit, and those collected from point C were taken with a Veihmeyer soil-sampling tube. All the samples were analyzed for water-soluble boron; in addition, the pH and specific conductance were determined for the samples for sampling point A, and sodium for the samples from line D-F. The results of these analyses are given in tables 4 and 5 and are shown graphically in figure 15.

These analyses demonstrate that there is an accumulation of soluble boron in the surface and near-surface soil. The concentration in the surface soil is greatest in the vicinity of the greasewood plants, and that in the near-surface soil is greatest between the depths of 1 and 2 feet. The data suggest that evapotranspiration by the greasewood is largely responsible for the accumulation and concentration of boron in the soil. The chemical analyses of the samples of the soil, roots, and leaves show that there is uptake of soluble boron by the roots, translocation of the solute through the roots and stems to the leaves, temporary storage in the leaves, and release to the soil. The process of release may include guttation, leaching by washing of the green leaves by rainfall, decay and leaching of the leaves after being shed, or a combination of these processes. Experiments with barley

TABLE 4.—Results of analysis of samples of undisturbed soil profile

[The nine samples collected from sampling point A were analyzed by the Nevada Soil Testing Laboratory, University of Nevada, Reno, Nev. All other samples were analyzed by the Water Resources Division Laboratory, U.S. Geological Survey, Menlo Park, Calif.]

Depth interval (ft)	pH	Specific conductance (micromhos at 25°C)	Boron (mg/kg)
<b>Sampling point A</b> [Sample Oct. 22, 1962]			
0 to 1	9.6	29,000	24
1 to 2	9.6	24,000	10
2 to 3	9.6	7,500	8
3 to 4	9.6	3,500	5
4 to 5	9.5	1,500	4
5 to 6	9.2	1,100	6
6 to 7	9.0	700	5
7 to 8	9.1	800	5
8 to 9	9.0	700	5
<b>Sampling point B—Dug pit</b> [Sampled Apr. 9, 1963]			
0.0 to 0.25			13
0.25 to 0.5			18
0.5 to 0.75			29
0.75 to 1.0			26
1.0 to 1.25			32
1.25 to 1.5			25
<b>Sampling point C</b> [Sampled Oct. 23, 1963]			
0.0 to 0.5			10.5
0.5 to 1.0			20.7
1.0 to 1.5			32.0
1.5 to 2.0			20.3
2.0 to 2.5			13.5
2.5 to 3.0			4.3
3.0 to 3.5			1.8
3.5 to 4.0			1.4
4.0 to 4.5			1.0
4.5 to 5.0			1.0
5.0 to 5.5			.9

plants grown in a boron solution show that boron may be lost from the leaves by both guttation and rainfall washing the leaves (Oertli, 1964). Following release from the leaves, boron seemingly is moved downward in the soil by infiltration of rainfall or melted snow water. As about two thirds of the annual precipitation falls during the winter months when evapotranspiration is low, the downward movement probably occurs at that time. During the spring and summer months, evapotranspiration dissipates the winter accumulation of water, leaving behind the boron and mineral salts.

The boron and specific conductance curves for sampling point A, shown in figure 15, illustrate this condition. The concentration of boron in the top 1.5 feet of the soil column is shown in greater detail by the curve for sampling point B, where the samples were collected at 3-inch depth intervals. The distribution of boron in

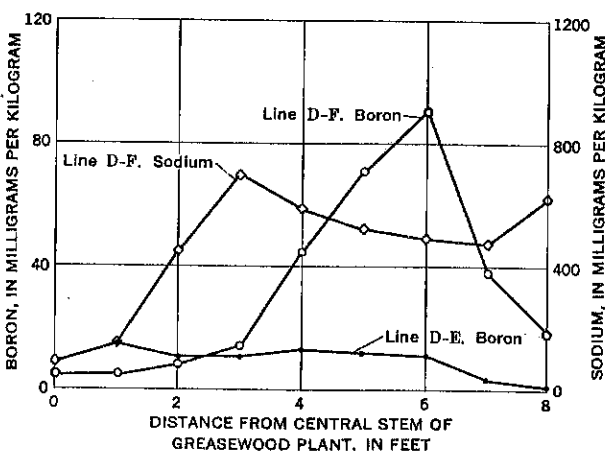
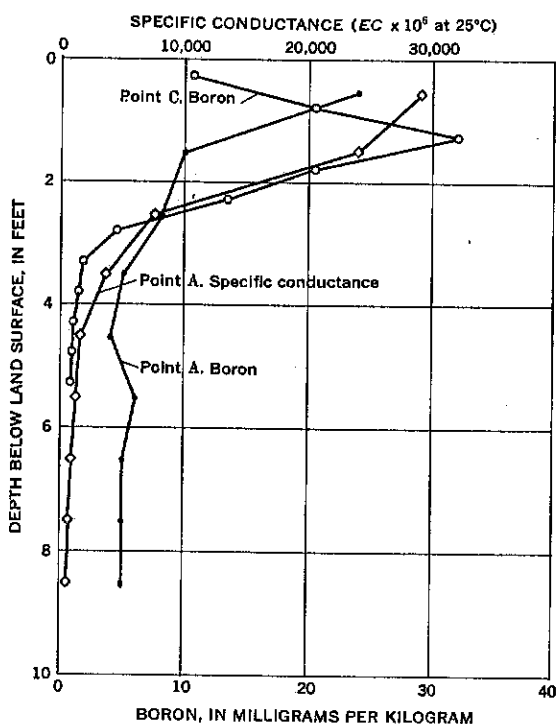
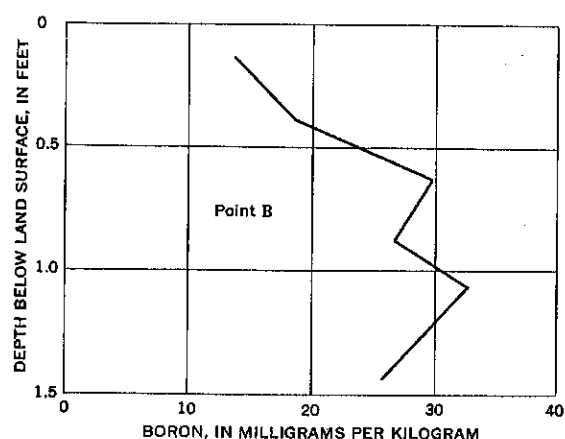


FIGURE 15.—Results of boron, sodium, and electrical-conductance determinations of soil samples collected from sampling points shown in figure 14.

TABLE 5.—Results of analysis of surface soil sampled to 3-inch depth at 1-foot intervals from central stem of a greasewood plant

[All samples were analyzed by the Water Resources Division Laboratory of the U.S. Geological Survey, Menlo Park, Calif.]

Distance from central stem (ft)	Soluble boron (mg/kg)	Sodium (mg/kg)
<b>Sampling line D-E</b> [Sampled Apr. 9, 1963]		
1	15	
2	10	
3	11	
4	13	
5	12	
6	11	
7	3.4	
8	0	
<b>Sampling line D-F</b> [Sampled Oct. 23, 1963]		
0	4.4	86.2
1	4.7	150
2	8.2	467
3	14.5	707
4	45	575
5	71	523
6	90	487
7	38	477
8	18.6	623

the soil column according to depth, with the concentration greatest in the top 2 feet, then decreasing with depth, suggests that little if any boron is moved downward to the water table by percolating rainwater. Thus, recharge to the ground water by direct precipitation seems to be negligible. If the boron had been more uniformly distributed throughout the soil column, with perhaps a slight concentration at the surface, downward movement of boron by percolating rainwater and of recharge to the water table by direct precipitation would be indicated.

Boron in the near-surface soil is believed to be responsible for the difficulty with growing crops on the terrace soil. Mr. H. T. Harrer, owner of the land of the Winnemucca test site, reported (oral commun., 1963) that 3 years of intensive irrigation were needed in order to establish a field of alfalfa on a nearby parcel of land. The heavy irrigation each year seems to have leached and reduced the boron content in the root zone to a concentration that did not affect growth of the alfalfa.

The large difference in boron between the two sampling lines D-E and D-F is believed to result from sampling at different times of the year. Line D-E, for which the boron content is the lower of the two, was sampled in April at the end of the winter season, whereas line D-F was sampled in October at the end of the growing season. A comparison of the precipitation for the

6-month periods preceding the sampling dates shows 3.37 inches for line D-E and 2.82 inches for line D-F, a difference of about half an inch. The mode of precipitation was also different. The 3.37 inches preceding the April sampling of line D-E occurred largely in the form of snow that accumulated during each storm and then melted slowly at temperatures above 32°F. Such a condition provides for a maximum infiltration opportunity that allows wetting of the soil to considerable depth and downward movement of boron. The 2.82 inches of precipitation preceding the October sampling of line D-F, fell as rain, in widely separated showers. With the exception of 1 day in July when 0.48 inches fell, the showers were light, none of more than 0.3 inch and most of them less than 0.25 inch. During the summer months, when the rainwater is dissipated rapidly by evapotranspiration, the soil is wetted only superficially, and so there is less opportunity for boron to migrate downward into the soil column than during the winter months.

#### LEACHING AS A CORRECTIVE MEASURE

The results of the chemical analyses of the soil and leaf samples indicated that the soil in the tanks was rich in boron, and that there was uptake of boron by the greasewood plants in quantities that damaged the plants. To assure continued growth and survival of the plants, a reduction of the boron content in the root zone was essential. The measure considered to be the simplest and most effective was to leach by backwashing. In this procedure, water was introduced into the bottom of the tank through the distribution system until the entire soil mass was saturated and water overflowed the tank. As the water moved upward through the soil, boron and other mineral salts were taken into solution and carried away in the effluent.

As the soil in both the greasewood and rabbitbrush tanks was similar in texture, and presumably similar in boron and mineral salts contents, both sets of tanks were leached, even though the rabbitbrush plants had not shown any signs of distress. Backwashing of greasewood tank 1 and rabbitbrush tank 1 began in late October 1962, and was nearly completed on November 5 when freezing temperatures effectively halted further operation for the year. Backwashing of the three remaining tanks, greasewood tank 2 and rabbitbrush tanks 2 and 3, was completed in April 1963.

During the summer of 1965, the rabbitbrush plants in the tanks began to show symptoms of distress. Leaf tip burn was quite noticeable, and toward the end of the growing season, there was some defoliation. The plants in the greasewood tanks, however, did not show any

symptoms indicating boron toxicity. The backwashing evidently had not been as effective in the rabbitbrush tanks as in the greasewood tanks, or the greasewood plants had a greater tolerance to boron than rabbitbrush. The latter explanation seems more appropriate. These symptoms of boron toxicity indicated that the rabbitbrush tanks needed to be backwashed a second time. Backwashing of all three tanks was completed in early April 1966.

Sampling of the soil in the tanks to determine the reduction of its boron content as leaching progressed was not practicable. Collection of soil samples at depth would have been exceedingly difficult and facilities for analytical determinations were not available at the site. In lieu thereof, the specific conductance (in micromhos at 25°C) of the effluent water was used as a measure of the effectiveness of the treatment.

The volume of water used for leaching and the rate at which it was added to each tank was measured with water meters. As soon as the soil mass in each tank was saturated, a 5-foot extension was attached to the supply pipe of the tank to provide a head for the upward movement of water through the soil. The rate of flow through the soil was not the same for all tanks of equal surface area; however, an approximately uniform flow through each tank was achieved by a rate of inflow adjusted to maintain a head of about 5 feet above the surface of the tank. The rate of inflow to greasewood tank 1 and rabbitbrush tank 1 in October 1962 was less uniform than the rates for greasewood tank 2 and rabbitbrush tanks 1, 2, and 3 in April 1963 and 1966. The difficulty was due largely to the low temperatures during the night causing ice to form on the surface of the tanks and in the surface soil.

Samples of the effluent, for analysis, were collected at the overflow point of each tank. Field determinations of the conductivity of the samples were made as they were collected. The results of the conductivity determination were used as a guide in selecting the samples of the effluent for chemical analysis. As shown in figures 16 and 17, the conductivities were high initially and decreased as the leaching progressed. Leaching was continued until the conductivity of the effluent had decreased to about 2,000 micromhos. The value of 2,000 micromhos was arbitrarily selected on the assumption that at that conductivity, the boron content of the soil in the root zone had been reduced to a level that was not harmful to the plants.

The results of chemical analysis of the effluent from greasewood tank 1 and rabbitbrush tank 1 are given in table 6. These analyses show a general decrease in concentrations of all the constituents as the leaching progressed. The results for rabbitbrush tank 1 are somewhat

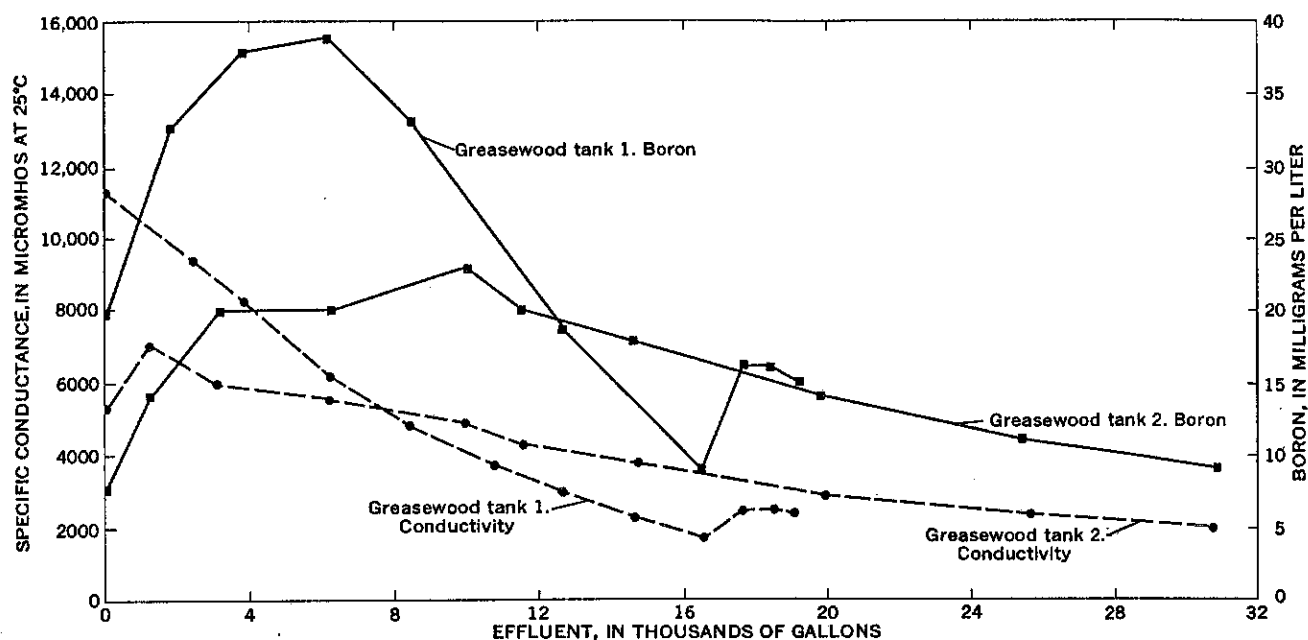


FIGURE 16.—Decrease in boron and specific conductance of the effluent from greasewood tanks 1 and 2 during leaching.

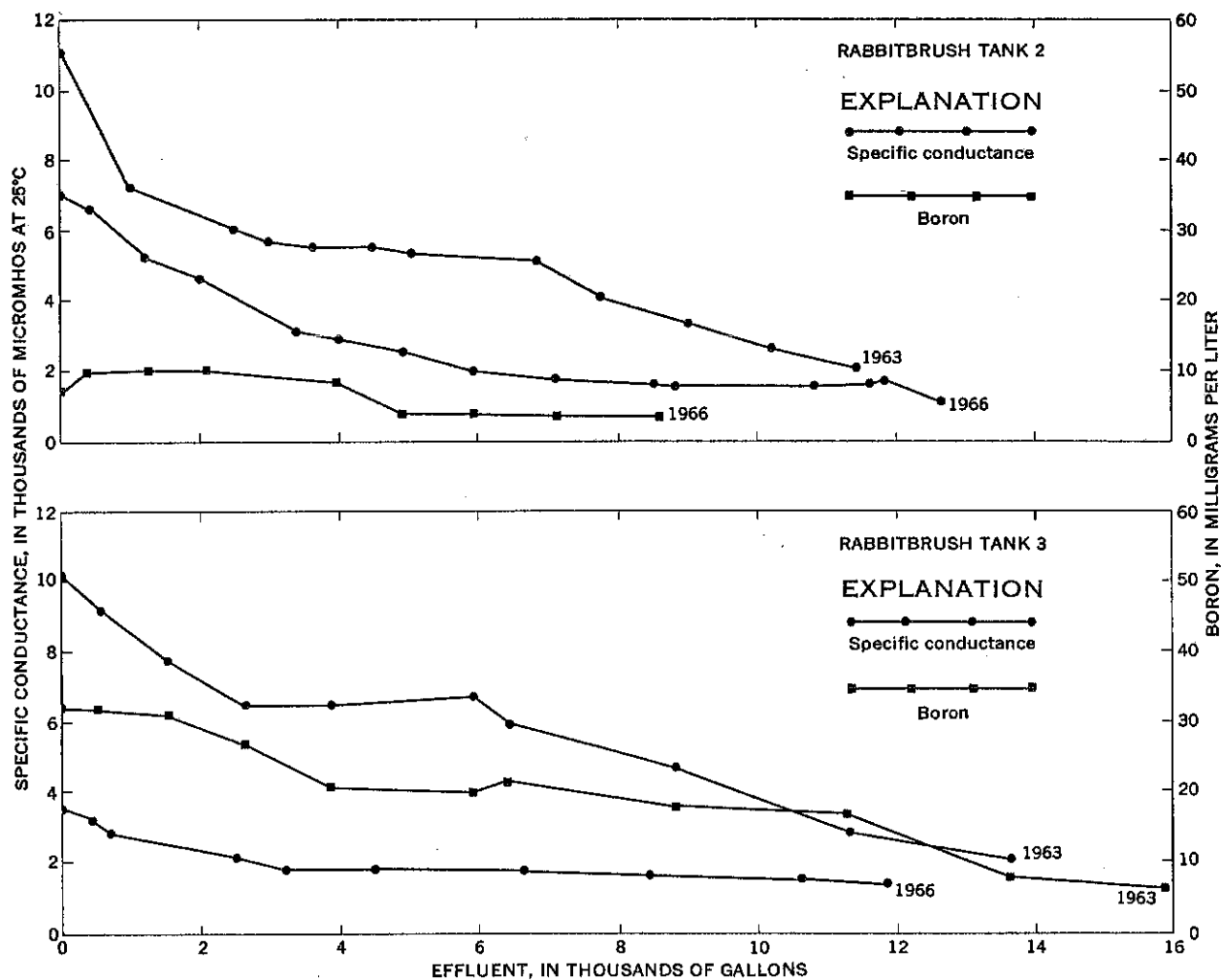


FIGURE 17.—Comparison of specific conductance and boron of the effluent from rabbitbrush tanks 2 and 3 for the leachings of 1963 and 1966.

erratic, because of different rates of circulation. Owing to the below-freezing temperature at night during leaching, regulation of the low rate of flow of the leach water was difficult. Regulation of the higher rate of flow into greasewood tank 1 was not a problem until near the last 48 hours of the operation. During the latter period, the rate decreased from about 79 gallons an hour to about 46 and then to about 32 gallons an hour. The effect was to increase the concentration of most of the constituents in the effluent, as shown in table 6. The increase in boron and conductivity is shown graphically in figure 11. Boron increased from 8.7 to 16 mg/l and conductivity from 1,720 to 2,450 micromhos with the decrease in rate of inflow from 79 to 46 gallons an hour. The increase was not unexpected, for with slower movement through the soil, the leach water was in contact with the soil grains for a longer period of time; thus, greater opportunity was afforded for the constituents to be taken into solution.

Less difficulty was experienced in maintaining a uniform flow through the tanks leached in April 1963. In greasewood tank 2, the rate averaged 224 gallons per hour, varying only about 2 gallons per hour during the period of leaching. In rabbitbrush tank 2, the rate averaged 70 gallons an hour, and for rabbitbrush tank 3, it was 99 gallons an hour.

Comparison of the specific conductance curves of the effluent for the leachings of April 1963 and April 1966, shown in figure 17, indicate that the effluent in 1966 was less concentrated. Boron determinations were made only for rabbitbrush tank 3 in 1963 and for tank 2 in 1966; so a direct comparison of the difference in the boron

content of the effluent from the two leachings is not available for either tank. It seems reasonable, however, to assume that, like the conductivity, the boron content of the effluent was less in 1966 than 1963.

The rates of flow through the tanks were smaller in 1966: 54 gallons an hour for rabbitbrush tank 2 and 81 gallons an hour for tank 3, a decrease of 16 and 18 gallons an hour, respectively. As a result, the leach water had a greater opportunity to take the soluble salts into solution. The decrease in concentration of the effluent in 1966, even though the opportunity to take more salts into solution was greater, indicates that the leaching of 1963 was effective in removing most salts; however, apparently the 1963 leaching did not reduce the boron content to a concentration that was not damaging to the plants. Because the plants in the greasewood tanks that were leached in 1962 and 1963 did not show any evidence of boron toxicity in 1965 or in 1966, the greasewood evidently has a higher tolerance to boron than does rabbitbrush.

#### FACTORS INFLUENCING EVAPOTRANSPIRATION RATES

Evapotranspiration was defined earlier as water withdrawn from soil by evaporation and plant transpiration. Evaporation from the soil surface generally is the smaller fraction of evapotranspiration. The results from the bare-soil tank studies at the Winnemucca test site indicated that the evaporation from soil was less than half the evapotranspiration from the vegetated tanks.

Transpiration by plants and evaporation from the soil

TABLE 6.—Quantity, rate of inflow to tank, and chemical analyses of samples of the effluent from greasewood tank 1 and rabbitbrush tank 1, October 1962

[Constituents in milligrams per liter]

Effluent (gal)	Elapsed time (hr)	Rate of inflow to tank (gph)	Conductivity (micromhos at 25°C)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO <sub>3</sub> )	Carbonate (CO <sub>3</sub> )	Sulfate (SO <sub>4</sub> )	Chloride (Cl)	Phosphate (PO <sub>4</sub> )	Boron (B)	pH
Greasewood tank 1														
0	0	—	11,300	68	25	2,830	326	4,060	59	1,690	1,270	24	20	8.32
2,150	20.5	105	9,400	50	21	2,500	243	4,720	143	854	663	44	33	8.42
3,780	37.0	99	8,170	30	16	2,180	191	4,210	245	606	475	52	37	8.62
6,140	60.0	103	6,180	15	8.5	1,630	137	3,090	280	358	285	48	36	8.80
8,440	85.0	92	4,750	11	4.8	1,190	101	2,240	290	225	182	39	33	8.91
10,700	109.0	94	3,740	—	—	—	—	—	—	—	—	—	—	—
12,570	133.0	86	3,020	11	3.9	740	60	1,420	172	135	96	27	19	8.90
14,370	157.0	83	2,820	—	—	—	—	—	—	—	—	—	—	—
16,460	181.0	79	1,720	28	9.8	373	32	818	59	102	66	13	8.7	8.63
17,570	205.0	46	2,450	11	3.1	587	42	1,300	54	116	68	23	16	8.40
18,330	228.5	32	2,490	7.2	1.9	597	41	1,340	44	117	66	23	16	8.40
19,090	253.0	31	2,370	6.5	2.3	567	41	1,160	103	104	67	23	15	8.78
Rabbitbrush tank 1														
0	—	—	6,550	13	18	1,630	90	2,320	202	793	508	9.0	12	8.83
550	23.5	23	6,430	18	11	1,710	79	3,330	108	507	356	12	18	8.48
1,820	51.5	46	6,020	24	10	1,720	82	3,070	103	591	488	15	25	8.48
3,060	110.0	19	3,460	47	16	766	37	1,330	0	333	296	6.5	8.6	8.10
3,710	133.5	14	4,150	43	15	972	42	1,600	0	404	364	8.5	11	8.04
4,320	211.5	13	1,890	54	16	366	22	750	0	198	152	2.9	3.3	7.99
4,630	235.5	9	5,210	43	11	1,250	56	1,870	34	645	528	12	13	8.33
5,100	284.0	18	3,840	44	17	864	40	1,410	7	443	390	7.9	8.0	8.23

occur in response to the same energy sources as evaporation from a water surface. The response, however, is modified by the physical characteristics of the soil and the physiological characteristics of the plants; the effects of the modifications are not fully understood. For a given climatic condition, with water nonlimiting, as for phreatophytes, the rate of transpiration depends on the species, cover density and plant size, stage of maturity, and tolerance to mineral salts in the soil and water. For a given plant species, the annual rate is affected by climatic conditions such as temperature, wind movement, humidity, solar radiation, rainfall, and length of growing season. Of these, temperature is the most important for it determines the warmth of the growing season and controls the length of it.

The growing season has been defined by the Phreatophyte Subcommittee of the Pacific Southwest Inter-Agency Committee (1966) as "the season that is warm enough for plants to grow." Generally it is considered as the period between the last killing frost in the spring and the first killing frost in autumn. The minimum temperature that constitutes a killing frost for one species may have little or no effect on more hardy species.

The four species of phreatophytes studied were hardy plants, native to the Humboldt River basin, and acclimated to the basin. Data on the minimum temperature conditions that would constitute a killing frost for these species are uncertain. A killing frost for them may be interpreted as that which damages the foliage severely enough to cause defoliation, thus restricting the rate of water use. It is not a killing frost in the sense that the plants are killed, for the shrubs are perennials that persist from year to year and survive below-zero temperatures during winter months. However, some generalizations may be made. Observations in the area indicate that the four transplanted species withstood, without apparent damage, temperatures of 32°F or slightly lower that severely damaged or killed less hardy plants such as alfalfa, garden and flowering ornamental plants. Threshold temperatures of 32°F, 28°F, 24°F and 16°F are reported regularly by the Weather Bureau as an aid for those people concerned with damage to plants of different degrees of hardiness. The threshold temperature that appears to stop growth in the four species studied is 28°F. This interpretation is based on observations of the plants and on a decrease in water use following minimums of 28°F.

The yearly periods between minimums of 32°F are shorter than those between minimums of 28°F. For comparisons of the lengths of the growing seasons controlled by minimums of 32°F and of 28°F the earliest and latest dates of these temperatures and the lengths

of the periods between them are shown in the following tabulation:

*Threshold temperatures*

Year	32°F			28°F		
	Latest	Earliest	Days	Latest	Earliest	Days
1962.....	June 5	Aug. 28	84	Apr. 30	Sept. 19	142
1963.....	May 12	Sept. 24	135	Apr. 20	Oct. 24	187
1964.....	May 21	Aug. 30	101	May 7	Sept. 19	137
1965.....	May 15	Sept. 9	117	May 6	Sept. 17	134
1966.....	June 3	Sept. 2	91	June 3	Oct. 4	123
1967.....	May 14	Sept. 14	123	May 14	Sept. 14	123
Average.....			108			141

The warmth of a growing season, of a month, or of any period of time may be described and compared on the basis of degree days—a degree day being 1° of the average daily temperature above a base of 32°F for 1 day. Thus an average temperature of 42°F for 1 day is equivalent to 10 degree days. The degree days by months and for the period April through October at the test site are given in table 7. The data in the table show that the warmth in the early and late months varies widely. For example, April 1967 was cooler by 354 degree days than April 1962 (equivalent to an average daily temperature difference of 11.8°F; October 1962 was warmer by 456 degree days than October 1966 (equivalent to an average daily difference of 14.7°F). In the midsummer months of June, July, and August, however, the range of difference was much less, being about 125 degree days for each month.

The relation of monthly draft on ground water (water added) to temperature during the period April through October 1966 for three of the species grown in the evapotranspiration tanks is shown in figure 18; the values are expressed in percentage of the seasonal total. The appearance of some new leaves and buds on the rabbitbrush and greasewood shrubs in April indicated plant activity and water use. Growth activity by the willows, however, was barely discernible.

During April, the draft by the rabbitbrush and greasewood plants was a little more than 2 percent of the total use for the season, while that for the willow plants was less than 1 percent. Evapotranspiration during

TABLE 7.—Comparative warmth for the period April 1 to October 31, 1962-67, by months, at the Winnemucca test site, in degree days above a base of 32°F

Month	1962	1963	1964	1965	1966	1967	Average
April.....	591	363	360	507	495	237	426
May.....	657	831	645	580	871	604	714
June.....	942	819	834	801	903	867	876
July.....	1,147	1,088	1,215	1,184	1,119	1,223	1,153
August.....	1,029	1,073	1,060	1,051	1,162	1,268	1,107
September.....	885	945	723	660	882	960	842
October.....	958	701	688	605	502	553	669
Total degree days.....	6,200	5,820	5,525	5,467	5,934	5,807	5,797

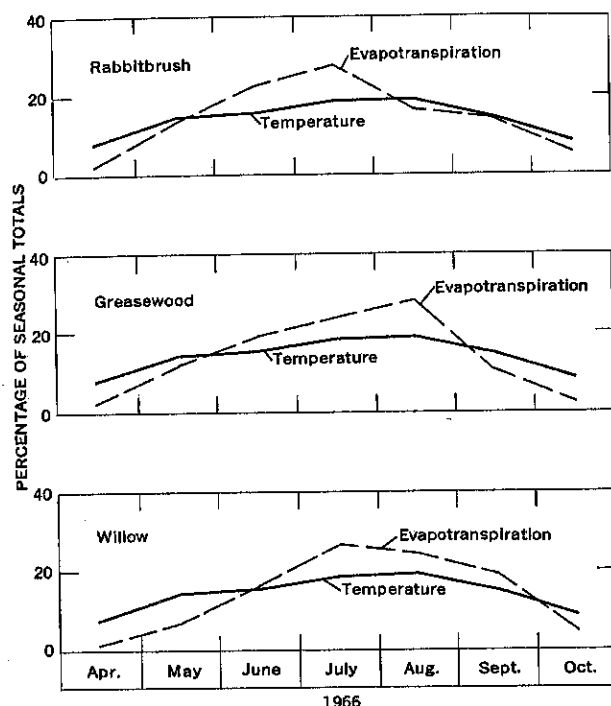


FIGURE 18.—Relation of monthly draft on ground water to temperature April through October 1966 for three species of phreatophytes. Monthly values of evapotranspiration and warmth in degree days are expressed in percentage of the seasonal totals.

May, June, and July increased at a rather uniform rate for the three species. The peak rate of ground-water use for rabbitbrush and willow occurred in July, but that for greasewood was not reached until August. The decrease in rate of use following the peaks was rapid for rabbitbrush and greasewood, but much slower for willow. The ground-water use by the rabbitbrush and greasewood during the peak month was 28 percent of the seasonal total; the ground-water use by the willows was about 27 percent. During the period June through August, the ground-water use by the rabbitbrush and willow was about 67 percent of the seasonal total and that by the greasewood about 72 percent, whereas the corresponding warmth was only 54 percent of the total for the season.

The graphic representation of evapotranspiration in figure 18 demonstrates for the three species of phreatophytes the rates of ground water use, the differences in rates at the beginning and end of the growing season, and the months of peak use. These differences emphasize the need for studies of evapotranspiration by species, for proper assessment of evapotranspiration discharge and, more importantly, the period and rate of draft on the ground-water reservoir.

Wind movement affects evapotranspiration by removing the humidity-laden air adjacent to the transpiring leaf and replacing it with air of lower humidity.

Wind also affects evaporation from soil and water surfaces in much the same manner.

Rainfall, as described earlier, is scant and generally occurs as showers of less than 0.5 inch. During rain periods, there is an increase in the humidity of the air that results in a reduction of the evapotranspiration rate. The principal effect of rainfall in the Humboldt River valley is its influence on the draft from the ground water by phreatophytes. During seasons of high rainfall, the draft from the ground water is reduced by the quantity of rain that enters the soil and becomes available to the plants as soil moisture, as well as by the lesser evapotranspiration rate resulting from increased humidity. Conversely, during periods of low rainfall, the draft on the ground water is greater, as there is little opportunity for replenishment of the soil moisture.

As evaporation from a water surface occurs in response to the same energy source as evapotranspiration, the seasonal evaporation from a standard evaporation pan may be considered as an index to the relative evapotranspiration for that growing season. Thus, when pan evaporation is high, evapotranspiration may be expected to be correspondingly high.

The values for the elements of climate (wind, rain, and pan evaporation) as observed at the Winnemucca test site during the April through October periods from 1962 through 1967 are given in table 8.

#### EXPRESSION OF EVAPOTRANSPIRATION LOSSES AND EXTRAPOLATION TO GROWTH AREAS

The transposition of evapotranspiration losses by phreatophytes from the place of measurement such as evapotranspiration tanks to natural growth areas involves many variables. The two most important are differences in climate and in plant growth. Other variables include differences in soil texture and fertility, kind and amount of salts in the soil, depth to the water table, and quality of the ground water. Consideration must also be given to the relative stage of plant development at the two locations. Studies at the Winnemucca test site of the relationship of water use to plant development of the four species of phreatophytes indicate that evapotranspiration was generally greater after the plants had become established and had entered a pe-

TABLE 8.—Climatological data for the April 1–October 31 period, 1962–67, at the Winnemucca test site

Year (April through October)	Wind move- ment (miles)	Rainfall (in.)	Pan evapora- tion (in.)
1962	11,383	1.36	62.04
1963	10,803	6.66	53.94
1964	9,555	5.21	56.60
1965	11,487	3.63	52.72
1966	9,120	1.64	66.79
1967	9,487	3.60	56.10

riod of vigorous growth than after the plants had reached maturity. The extrapolation of evapotranspiration losses from immature phreatophytes to areas of mature growth would result in estimates that would be too large.

Realistic transposition of values for evapotranspiration losses from the place of measurement to natural stands of phreatophytes is as important as determination of the losses. The two methods commonly used are based on (1) area and (2) volume of foliage.

#### AREAL METHOD

Until about 1950, the usual method of expressing evapotranspiration was on an areal basis, that is, depth over a unit area, as acre-inches or acre-feet per acre. Evapotranspiration expressed on an areal basis describes the water use of a vegetated area for the existing growth condition without any indication as to the growth condition. Thus extrapolation on an areal basis is valid only when the conditions of growth, climate, soil, water supply, and water quality are similar. Generally, when the experimental studies are situated within or adjacent to the growth area under consideration, the only variables that need to be considered are the variations in plant growth and depth to water. Variations in plant growth are not uncommon in stands of phreatophytes. The plants may range in size from seedlings to mature plants, and growth density may range from a few percent to 100 percent. As a result, an appreciable error may be introduced into the computation of the water use by a natural stand when the conditions of growth for the measurement-area values are not known. In the past, adjustments for marked differences in growth conditions were made arbitrarily by assuming a linear relationship between evapotranspiration and variation in cover density. The validity of this assumption is doubtful, as available fragmentary data suggest a greater use when cover density is in the 80 to 90 percent range than that indicated by a direct proportion. This may be due, in part, to the "oasis effect." More information is needed on the relation of evapotranspiration rates to variations in cover density so that the extrapolation may be made more realistically.

#### VOLUME-OF-FOLIAGE METHOD

To avoid some of the difficulties and uncertainties inherent in the areal method, the volume-of-foliage method was developed. In this method the evapotranspiration loss or water use is expressed as a unit quantity per unit of foliage volume. The method presumes that transpiration, by a plant species, is proportional to the total transpiring leaf area and thus is proportional to the foliage volume. Transpiration rates vary for differ-

ent plant species, in proportion to the leaf area and to the rate per unit of leaf area. The transpiration rate per unit of leaf area has been found to differ markedly among species (Tomanek and Ziegler, 1962).

The volume-of-foliage method requires detailed measurements of cover density and thickness or canopy depth for the computation of foliage volume. The measurements for volume determination of the growth in the tanks were made by the techniques and to the standards outlined in the manual by Horton, Robinson, and McDonald (1964) for surveying phreatophyte vegetation.

Evapotranspiration on a volume-of-foliage basis may be expressed as acre-feet of water per acre-foot of foliage or in cubic-foot units. This method obviates the corrections for differences in plant growth, except possibly for growth areas of low density. In these latter areas, the method may have limitations due to the "oasis" effect, and this facet needs further study.

The evapotranspiration-tank studies were designed and the required data were collected so that the evapotranspiration rates could be calculated by both methods.

#### RESULTS OF EVAPOTRANSPIRATION STUDIES

The evapotranspiration data for the four species of phreatophytes and the bare-soil tank are tabulated in table 9 for the two methods and for the different water levels. The two sets of graphs in figure 19 depict evapotranspiration—computed by the areal and the volume-of-foliage methods—during the five seasons 1963 through 1967, together with the operating water levels. Graphs are shown only for those tanks for which the records of water use were unbroken over the 5 years; those for greasewood tank 2, willow tank 3, and wild-rose tank 3 are not shown. In the graph of evapotranspiration based on the areal method, the amounts of the three sources of water that make up the total evapotranspiration loss—ground water, soil moisture, and rainfall—are shown for each tank. The graph of the volume-of-foliage method shows only the total evapotranspiration loss. The evapotranspiration rates for the different tanks and the factors that influence them will be discussed separately by species.

#### GREASEWOOD

The decrease in evapotranspiration from 1963 to 1964 is believed to have resulted from the 1-foot lower water level in 1964 and the shorter and cooler growing season. Both tend to reduce the water use. The period between the minimum temperature of 28°F was 50 days less in 1964 than in 1963, and the period April through October was 295 degree days cooler. The slight decrease from 1964 to 1965 seems to be due largely to the lower-

## STUDIES OF EVAPOTRANSPIRATION

TABLE 9.—*Evapotranspiration by four species of phreatophytes grown in tanks at the Winnemucca test site and evaporation from bare soil during the growing seasons 1963-67*

Year	Depth to water level in feet	Sources of water in acre-feet per acre			Evapotranspiration		Remarks
		Rainfall	Soil moisture	Water added	Acre-feet per acre	Acre-feet of water per acre-foot of foliage	
Greasewood							
1963 <sup>1</sup> -----	5.0	0.44	0.48	0.89	1.81	1.70	Average of 2 tanks.
1963 <sup>1</sup> -----	5.0	.44	.44	.90	1.78	1.45	Tank 1.
1964-----	6.0	.40	.32	.53	1.25	1.06	Average of 2 tanks.
1964-----	6.0	.40	.26	.56	1.22	.91	Tank 1.
1965 <sup>2</sup> -----	7.5	.30	.42	.42	1.14	.88	Do.
1966-----	7.6	.14	.24	.83	1.21	1.04	Do.
1966-----	6.2	.14	.25	.98	1.37	1.35	Tank 2.
1967-----	7.8	.30	.43	.56	1.29	1.10	Tank 1.
1967-----	7.8	.30	.64	.62	1.56	1.49	Tank 2.
Rabbitbrush							
1963 <sup>1</sup> -----	5.0	0.44	0.23	1.52	2.19	3.22	Average of 3 tanks.
1964-----	5.0	.40	.13	1.09	1.62	1.94	Do.
1965-----	5.0	.30	.15	.62	<sup>3</sup> 1.07	<sup>3</sup> 1.04	Do.
1966-----	5.3	.14	.43	1.06	1.63	1.42	Do.
1967-----	6.2	.30	.43	1.01	1.74	1.25	Do.
Willow							
1963 <sup>1</sup> -----	5.0	0.44	0.27	3.23	3.94	0.94	Average of 3 tanks.
1963-----	5.0	.44	.27	2.89	3.60	.93	Tank 1.
1963-----	5.0	.44	.28	2.97	3.69	.84	Tank 2.
1964-----	5.0	.40	.20	1.81	<sup>4</sup> 2.41	<sup>4</sup> .61	Average of 3 tanks.
1964-----	5.0	.40	.10	1.76	<sup>4</sup> 2.26	<sup>4</sup> .66	Tank 1.
1964-----	5.0	.40	.23	1.80	<sup>4</sup> 2.43	<sup>4</sup> .54	Tank 2.
1965-----	5.7	.30	.29	1.48	2.07	.57	Tank 1.
1965 <sup>5</sup> -----	3.5	.30	.15	2.13	2.58	.49	Tank 2.
1966-----	5.8	.14	.28	2.30	2.72	1.26	Tank 1.
1966-----	4.2	.14	.22	3.19	3.55	.91	Tank 2.
1967-----	5.4	.30	.25	1.55	2.10	.99	Tank 1.
1967-----	4.1	.30	.24	1.85	2.39	.56	Tank 2.
Wildrose							
1963 <sup>1</sup> -----	5.0	0.44	0.20	0.77	1.41	0.92	Average of 3 tanks.
1963-----	5.0	.44	.14	1.04	1.64	1.00	Tank 1.
1963-----	5.0	.44	.21	.69	1.34	1.33	Tank 2.
1964-----	5.0	.40	.15	.84	1.39	.65	Average of 3 tanks.
1964-----	5.0	.40	.10	.86	1.36	.73	Tank 1.
1964-----	5.0	.40	.14	.89	1.43	.76	Tank 2.
1965-----	5.0	.30	.10	.83	1.23	.76	Tank 1.
1965 <sup>5</sup> -----	4.2	.30	.18	1.26	1.74	.90	Tank 2.
1966-----	5.9	.14	.19	1.23	1.56	1.40	Tank 1.
1966-----	4.2	.14	.24	1.75	2.13	1.47	Tank 2.
1967-----	6.1	.30	.21	1.08	1.59	1.17	Tank 1.
1967-----	4.4	.30	.16	1.46	1.92	.94	Tank 2.
Bare soil							
1963 <sup>1</sup> -----	2.2	0.44	0.03	0.30	0.77	-----	
1964-----	1.9	.40	---.03	.63	1.00	-----	
1965-----	2.3	.30	---.01	.23	.52	-----	
1966 <sup>6</sup> -----	4.0	.14	.04	.18	.36	-----	

<sup>1</sup> May 1 to October 20.<sup>2</sup> Membrane in tank 2 perforated in August 1965.<sup>3</sup> The decrease in water use in 1965 may reflect slower growth caused by an accumulation of salts in the root zone. Their presence was indicated by tip burn of the leaves, and by a change in color of the foliage during the growing season.<sup>4</sup> Plants damaged, and some stems dead, as a result of rabbits gnawing the bark of the plants.<sup>5</sup> Tank 3 discontinued in 1965.<sup>6</sup> Unmeasured water entered tank 1967.

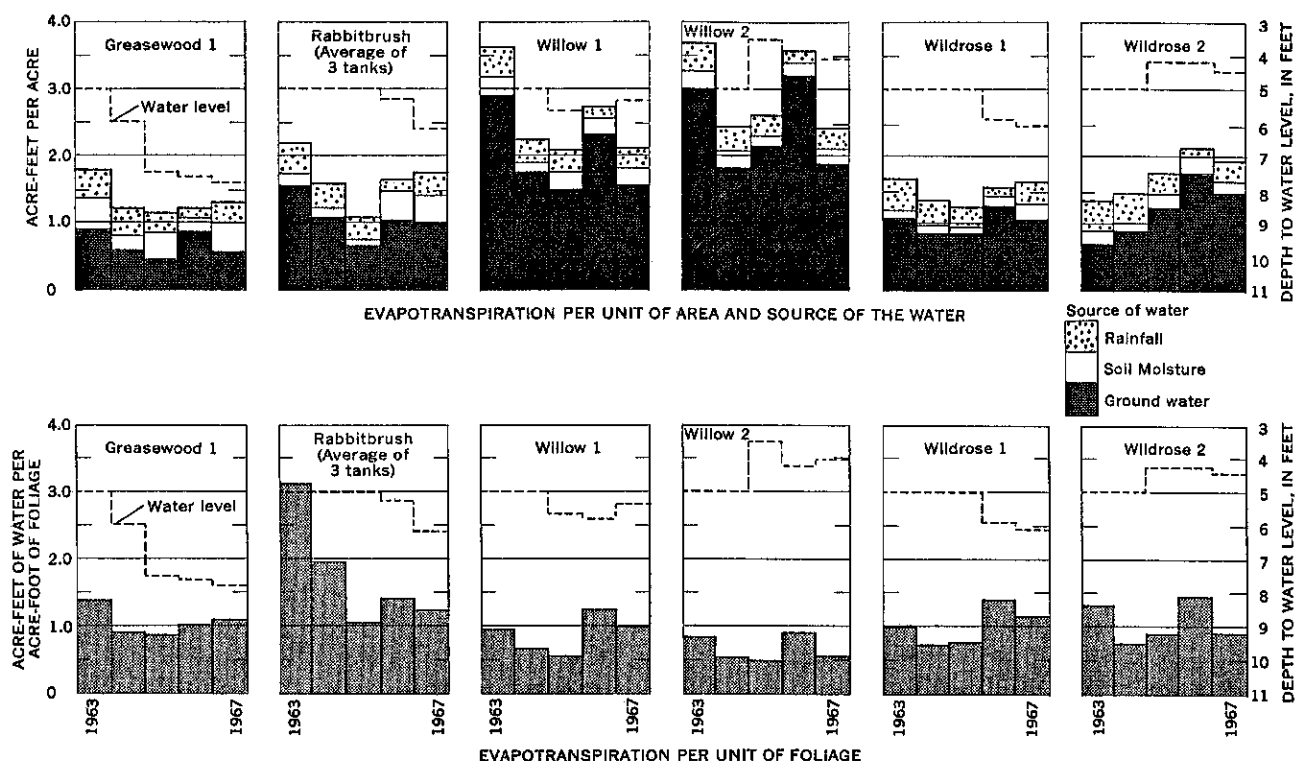


FIGURE 19.—Evapotranspiration by four species of phreatophytes during the growing seasons 1963 through 1967 for indicated depth of water level.

ing of the water level from 6.0 to 7.5 feet below the surface of the tank, as the length and warmth of the two growing seasons were comparable. The differences in the period between minimums of 28°F was only 3 days and in growing season warmth was 38 degree days. Evapotranspiration increased a small amount in 1966 and again in 1967. During these 2 years, the water level was only slightly deeper than in 1965; the periods between 28°F averaged 11 days less than in 1965, but the growing season was warmer by 447 degree days in 1966 and 320 degree days in 1967. During at least a part of 1965 and in 1966 and 1967, the root system of the plants in all probability had become adjusted to the water environment of the 7.5- to 7.8-foot water levels. Thus it seems that the length and warmth of the growing season exert a greater effect on evapotranspiration of greasewood than does a lowering of water level in the 5.0- to 7.8-foot range.

The evapotranspiration values for greasewood are believed to be representative for plants in the Humboldt River basin having approximately similar growth and water-level conditions. The average value for tank 1 for the four seasons 1964 through 1967 for water levels from 6.0 to 7.8 feet was 1.21 acre-feet per acre and 0.98 acre-foot per acre-foot of foliage. Ground water supplied 50 percent of this water, rainfall 23 percent, and soil moisture 27 percent. For tank 2, which had about 100 cubic feet less foliage, the evapotranspiration aver-

aged 1.46 acre-feet per acre and 1.42 acre-feet per acre-foot of foliage during the 1966 and 1967 seasons, for water levels in the depth range of 6.2 and 7.8 feet. Ground water supplied 55 percent of the water, rainfall 15 percent, and soil moisture 30 percent.

#### RABBITBRUSH

The decrease in the evapotranspiration rate from 1963 through 1965 probably resulted largely from the adverse effect of boron that still remained in the root zone in toxic amounts after leaching. Climatic effects such as the shorter and cooler growing seasons were doubtless contributing factors, but the impact was masked by the deleterious effect of the boron. The increase in water use in 1966 and 1967 is largely the result of leaching of the tanks and removal of the boron in the spring of 1966. The warmer growing seasons of 1966 and 1967 were an important factor also.

The evapotranspiration values for rabbitbrush, like greasewood, are believed to be representative for that plant in the Humboldt River basin under similar conditions. The average value, for the three tanks for the 1964, 1966, and 1967 seasons for water levels of 5.0-6.2 feet is 1.66 acre-feet per acre and 1.54 acre-feet per acre-foot of foliage. The 1963 and 1965 seasons were not included in the average because the plants were not mature in 1963, and the adverse effect of boron was ap-

parent in 1965. Of the 1.66 acre-feet per acre-foot, 64 percent was supplied from ground water, 17 percent from rainfall, and 20 percent from soil moisture.

#### WILLOW

The large decrease in evapotranspiration in the two willow tanks from 1963 to 1964 was caused largely by damage to the plants by rabbits during the winter of 1963-64. Evapotranspiration continued to decrease in tank 1 in 1965 while it increased in tank 2. The differences are ascribed to the changes in water levels. In tank 1, the water level was lowered from 5.0 to 5.7 feet, while the water level in tank 2 was raised from 5.0 to 3.5 feet below the surface of the tank. As other conditions were the same, the difference in evapotranspiration can be accounted for only by the lower and higher water levels.

Evapotranspiration in 1966 was appreciably higher in both tanks than in either 1964 or 1965. The water level in tank 1 was virtually unchanged from 1965 and in tank 2 was lower by 0.7 foot. The increased evapotranspiration was due to the warmer growing season, especially during the months May through September, the period of active willow growth. This period was warmer by 562 degree days in 1966 than in 1965.

Evapotranspiration in both tanks was markedly less in 1967 than in 1966. As the differences in water levels and in the warmth of the May through September period were relatively small, some other explanation must be sought to explain the decrease. As shown in table 1, the differences in cover density and foliage volumes between 1966 and 1967 were small. Maturation of the plants or concentration of deleterious salts in the root zone in toxic amounts provide the best explanations of the decrease. The decrease is attributed, however, to the adverse effect of the salts because the plants, which had been planted in 1960, were considered to have reached maturity by 1963 and certainly had by 1964. The water supplied to the tanks shown in table 4, although low in dissolved solids, is highest in sodium. It is conceivable that the alkali salts in the supply water may have accumulated in the root zone and reached a concentration in 1967 that affected the use of water by the plants. Willows have a low tolerance for alkali salts, and the threshold tolerance may have been exceeded in 1967. Unfortunately data are not available to indicate the threshold tolerance of willows to alkaline conditions.

The striking feature of evapotranspiration by willow shown in figure 19 is the heavy draft on ground water, which was the highest for the four species studied. For the 2 years when evapotranspiration was highest, ground water supplied to the tanks averaged 83 percent of the total water use; in the 3 years of lower evapotranspira-

tion—1964, 1965, and 1967—ground water supplied to the tanks averaged 76 percent of the total water use. These data indicate that draft on the ground water by willow is relatively independent of rainfall. Thus, in 1963, the year of highest seasonal precipitation, rain accounted for 12 percent of the total water use, and in 1966, the year of lowest seasonal precipitation, rain accounted for only 5 percent of the water use. In the other 3 years, seasonal rainfall averaged 15 percent of the water use.

Excluding the 2 years 1964 and 1967, when water use seems to have been adversely affected by damage by rabbits and an alkaline condition in the root zone, the average evapotranspiration for the two tanks was 3.03 acre-feet per acre and 0.83 acre-foot per acre-foot of foliage. Ground water supplied 82 percent, rainfall 10 percent, and soil moisture 8 percent of the total evapotranspiration during these 3 years.

#### WILDROSE

The causes of the differences in evapotranspiration in the wildrose tanks are not as apparent as for the other three species. The decrease in tank 1 from the 1963 to the 1965 season may be the result of the cool seasons of 1964 and 1965. The depth to the water level remained unchanged at 5.0 feet during this period. In tank 2 there was a slight increase in evapotranspiration from 1963 to 1964, while the depth to the water level remained unchanged. The slight increase, in contrast to the decrease in tank 1, may have been due to the 90 cubic feet increase in foliage volume. In 1964 the water level in tank 2 was raised 0.8 foot, from 5.0 to 4.2 feet below the surface of the tank, and remained at that level through 1966. The increase in evapotranspiration in these 2 years is believed due to the higher water level in 1965 and to the warmer growing season in 1966. In tank 1 the water level in 1966 was lowered 0.9 foot from 5.0 to 5.9 feet. Normally this would have caused a decrease in evapotranspiration; however, the effect of the warm growing season seems to have more than compensated for the effect of the greater depth to water. In 1967, with slightly lower water levels in both tanks, evapotranspiration increased slightly in tank 1 and decreased slightly in tank 2.

The average evapotranspiration for the 5 years of record was 1.48 acre-feet per acre and 1.01 acre-foot per acre-foot of foliage for tank 1, which had the deeper operating water levels, and 1.71 acre-feet per acre and 1.08 acre-foot per acre-foot of foliage for tank 2, which had the higher operating water levels. Over the 5-year period, ground water supplied 70 percent, rainfall 20 percent, and soil moisture 10 percent of the total evapotranspiration. Wildrose was second to willow in its use

of ground water and utilized less soil moisture than any of the other three species.

#### BARE SOIL

The values of evaporation from bare soil given in table 9 show that evaporation from a bare-soil surface is less than half the evapotranspiration losses shown for the phreatophytic vegetation. During the 4 years of record, with the depth to the water level ranging from 1.9 foot to 4.0 feet below the surface of the tank, draft from the ground water, based on the water added to the tank, was 51 percent of the total loss, while rainfall supplied 48 percent. Evaporation for the 4 years ranged from 0.36 to 1.00 acre-foot per acre and averaged 0.66 acre-foot per acre. As expected, the loss was least at the deepest water level, 0.36 acre-foot per acre from a 4.0-foot water level, and 1.00 acre-foot per acre with a 1.9-foot water level. Loss from the ground water ranged from 0.18 to 0.63 acre-foot per acre and averaged 0.34 acre-foot per acre. During June of 1963, 1964, and 1965, some recharge to the ground water in the tank resulted from showers of 0.50–0.75 inch, as indicated by small rises of water level in the tank following showers of one-half inch or more. No large showers occurred in 1966, and water from the light summer rains seemingly did not percolate to the ground water in the tank.

#### SUMMARY

One of the largest unknowns in the water budget of the Winnemucca reach of the Humboldt River is the consumptively wasted water from areas of phreatophytes of low-beneficial usefulness. Studies were begun in 1959 to evaluate the unit annual consumptive waste of four of the common woody phreatophytes—greasewood, rabbitbrush, willow, and wildrose—growing in the reach. The water use by these shrubs was determined by growing the plants under controlled conditions in 11 evapotranspiration tanks that ranged in size from 10 feet square and 7 feet deep to 30 feet square and 10.5 feet deep. In addition, evaporation was determined from unplanted bare soil in a tank 10 feet square.

Evapotranspiration was computed as the total quantity of water added to the tanks, the rainfall on the tanks during the growing season, and the reduction in soil moisture between the beginning and end of the growing season. Plant growth, development, and water use were adversely affected during some years by damage to the plants and by boron toxicity. Damage resulted from rabbits gnawing the bark of willows and from insects feeding on the leaves of greasewood and willows. Boron toxicity resulted from concentrations of soluble boron in the soils at the root zones of greasewood

and rabbitbrush. The causes of plant damage were corrected by catching and removing rabbits from the test site enclosure and by spraying the insect infestation with insecticide. Boron toxicity was corrected by reducing the concentrations of boron in the root zone through backwash leaching.

Foliage volumes, a measure of plant growth and development, were computed from transects across the tanks. They provided a basis for comparison of growth by species from year to year and seasonally between individual tanks of the same species. Foliage volumes also provided a basis for expressing water use in terms of foliage.

Climatic conditions and the lengths of the growing seasons affected the annual evapotranspiration rates. The most important climatic element was temperature. The highest water use by the plants occurred in June, July, and August when more than two thirds of the seasonal use took place. The least water use occurred in April and October when the use each month was approximately 2 percent of the seasonal use.

Evapotranspiration rates were computed by two methods and expressed in two different units—on an areal basis (in depth over a unit area of land) and on a volume of foliage basis (in volume of water per unit volume of foliage). Evapotranspiration expressed areally gives no indication of the growth conditions for which the information was obtained. When expressed by volume of foliage, however, the growth conditions, which are represented by the product of the cover density and thickness of foliage for a unit area, are inherent in the expression, because the evapotranspiration is presumed to be proportional to the transpiring leaf area, and thus is proportional to the foliage volume. In the extrapolation of experimental data to field areas of dissimilar growth, the volume-of-foliage method is preferable as less uncertainties are involved than in the areal method.

The results of the studies ranged rather widely between species. For the same species the seasonal results varied, differences being due to the operating water level, the warmth of the growing season, and plant response to the effects of damage or alleviation of damage by rabbits, insects, and boron toxicity. Draft from the water table (equivalent to the water supplied to the tanks) varied with the seasonal rainfall, being greatest when the rainfall was scant and least when it was copious.

The data obtained in the evapotranspiration tank studies at the Winnemucca test site indicate that during 1963–67 average water use by greasewood ranged from 1.21 to 1.45 acre-feet per acre in tanks 1 and 2, of which

50 to 55 percent was supplied by ground water. The average evapotranspiration by rabbitbrush for 3 years, 1964, 1966, and 1967, was 1.66 acre-feet per acre, of which 64 percent was supplied by ground water. Evapotranspiration by willow was the highest of the four species, amounting to 3.03 acre-feet per acre for the two tanks during the 1963, 1965, 1966 seasons. It was also the highest user of ground water, obtaining 82 percent of its water from that source. Wildrose was the second highest user of ground water and the smallest user of soil moisture. Evapotranspiration by wildrose averaged 1.48 acre-feet per acre in tank 1 with operating levels ranging from 5.0 to 6.1 feet below the surface of the tank, and 1.71 acre-feet per acre in tank 2 with operating water levels ranging from 4.2 to 5.0 feet below the surface of the tank. On the average, ground water supplied 70 percent of the total use, and soil moisture only 10 percent.

### SOIL-MOISTURE DETERMINATIONS

By A. O. WAANANEN

The woody phreatophytes under study in the evapotranspiration tanks at the Winnemucca test site of the Humboldt River Research Project receive part of their seasonal water supply from soil moisture in the unsaturated zone. Precipitation and water added to the tanks during the growing season constitute the principal part of the water supply, but water from winter precipitation stored as soil moisture above the water table may represent a significant part of the water budget. Evaluations of evapotranspiration water use thus would be incomplete without information on the quantities of water provided from this soil moisture.

Initial observations of the water content of the soils in the evapotranspiration tanks were made in September 1961 using a neutron-scattering soil-moisture meter in access tubes installed in each tank for this purpose. A regular program of observations was started in April 1962.

The purpose of the soil-moisture observations was to determine the water content of the soils at the beginning and end of the growing season and at selected intervening times to define seasonal variations. The change in water content during the growing season thus provides a measure of the volumes of water provided to the plants from this source. Data were obtained also at several sites on the Humboldt River flood plain near Winnemucca, including one tube installed within the Winnemucca test site, to explore the range of variations in water content in the zone of fluctuation of the water table adjacent to the river and in the unsaturated soils near the land surface.

### SOIL-MOISTURE OBSERVATIONS AT THE WINNEMUCCA TEST SITE

#### EQUIPMENT AND PROCEDURE

The neutron meter provides a convenient means for determining changes in the moisture content of soils. After installation of suitable access tubes, rapid and repetitive observations can be taken in the tubes at any time as the soils are not subjected to further disturbance. Differences in the quantity and distribution of moisture in the soils as shown by subsequent observations represent a measure of the changes in the water content.

The neutron-scattering soil-moisture meter used consists of a depth probe equipped with a 28-milligram actinium-beryllium neutron source, detector tube, and preamplifier connected by cable to a portable counting device (scaler). The probe is stored and transported in a shield that serves also as a standard for relating meter counts to water content and for checking meter operation. In normal use, the probe is lowered in an access tube to desired depths. Fast neutrons emitted by the source enter the surrounding soil materials and are moderated by hydrogen ions present principally in the moisture in the soil. Thermal (slowed) neutrons are detected and counted. The observed count varies directly with the number of hydrogen ions in the soil, contained principally in the water. The effective diameter of the sphere of influence of the neutron source varies inversely with the water content of the soil. Appropriate calibration relations permit conversion of the observed counts to moisture content in percent by volume or to weight of water per unit of volume.

Figure 20 presents a view of the neutron-meter scaler, probe, and shield as well as soil augers and types of access tubes used in the soil-moisture studies. A typical application of the neutron meter in the tank studies is illustrated in the generalized section of an evapotranspiration tank shown in figure 21.

Initially only one access tube was installed in each of the tanks planted to woody phreatophytes and in the bare-soil tank. These were placed near the center of the tanks but not over any conduit of the water distribution systems. Additional tubes were installed later in the two 30-foot tanks planted to greasewood and in one of the 20-foot tanks planted to rabbitbrush to provide information also on the lateral distribution of moisture in the tanks. Four tubes were installed in greasewood tank 1, of which two were placed directly over units of the water system. Tubes of aluminum (2-inch outside diameter, 0.065-inch wall) or alloy steel (1.75-inch outside diameter, 0.035-inch wall) were used, and these were sealed at the bottom so that observations could be taken at depths below the water level in the tanks. The tubes in the larger tanks were of sufficient length to

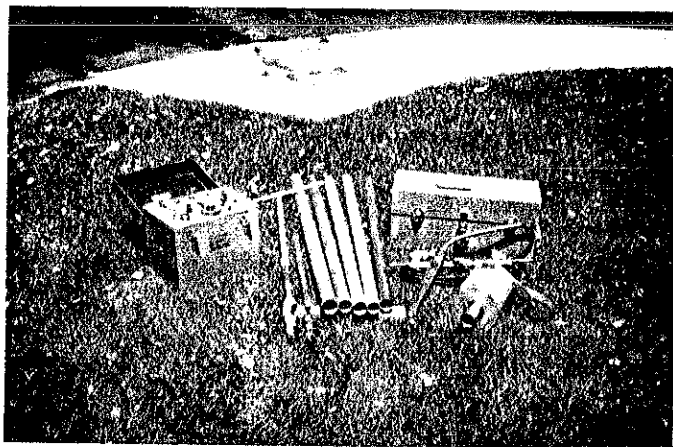


FIGURE 20.—Neutron-meter scaler, probe, and shield, with soil augers and typical access tubes.

permit sampling nearly the full depth of the tanks, but those in the shallower 10-foot tanks limited sampling to 60-inch profiles.

Figure 22 presents a view of the neutron meter set up for use in greasewood tank 1 in July 1962. The access tubes installed in the rabbitbrush tanks are visible in the photograph (fig. 23) taken July 1963. These photographs also give some indication of the relative plant growths at the respective times.

Soil-moisture observations were taken in the access tubes at half-foot depth intervals below the land surface, and moisture contents were computed in successive 6-inch-thick zones. The observed values of water content, representing the integrated result for spherical volumes of soil ranging from 12 to 30 inches in diameter depending on the moisture present, were used as the mean for each zone. Near the land surface, the sphere of influence of the source intersects the air-soil interface, and the inclusion of some air in the observed volume results in a reduction in the neutron count. Therefore, moisture in the top increment was computed for a 9-inch depth using the moisture value observed

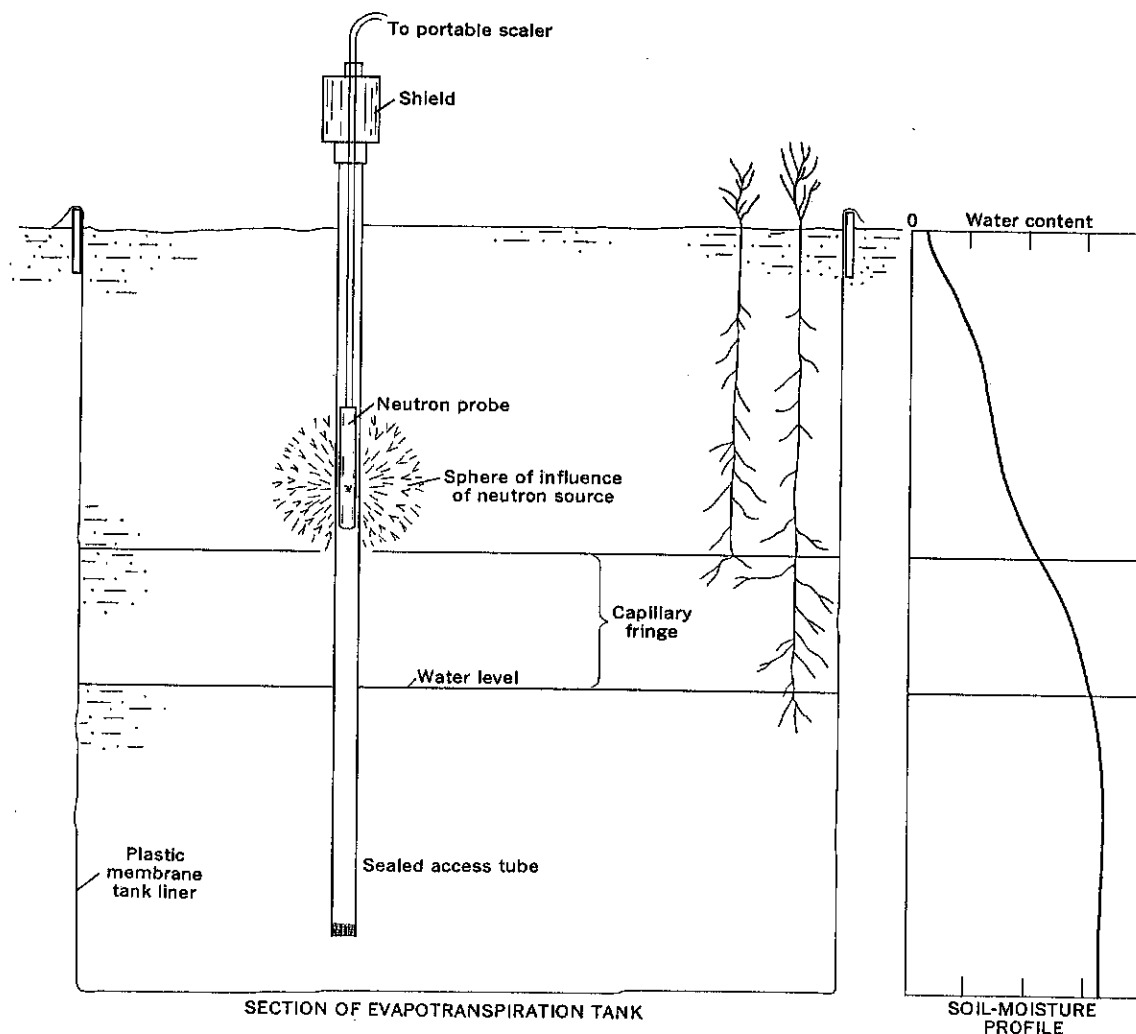


FIGURE 21.—Generalized section of evapotranspiration tank showing neutron-meter depth probe in access tube for soil-moisture observations, and typical soil-moisture profile.

at the 6-inch depth. Tests had indicated that this procedure yielded reasonably reliable values as the reduced count was offset by the moisture differences at the 6-inch and the 4½-inch mid-increment depths. This procedure obviated the need for the precise determination of moisture at the surface.

Calibration relations for the specific soils at the Winemucca test site were reviewed. The heavy flood-plain soils in the meadow area are well leached, and the normal calibrations for the tubes used were deemed applicable. The terrace sands and gravels, in place, contain alkali salts and some boron, as discussed in the main report, that vary in concentration with depth and that have the greatest concentrations in the upper 2-4 feet of the soil profile (fig. 13). Boron is a neutron moderator, and its presence in appreciable concentrations may cause sufficient absorption to reduce the meter count for given water content. Some other salts present in the soils also may have some moderating influences. The materials in the greasewood and rabbitbrush tanks (fig. 2), however, were mixed during the construction of the tanks, and the pattern of the concentrations of salts is uncertain. Gravimetric sampling indicated a

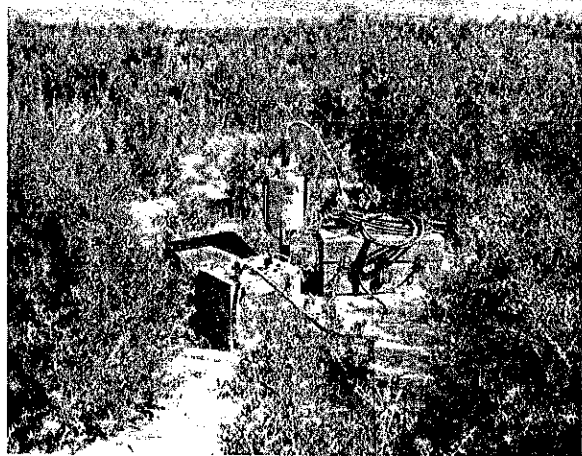


FIGURE 22.—Neutron meter set up for use in greasewood tank 1.

small effect on the calibration relations, but definition was inconclusive owing to the mixing of the soils and the variations with time resulting from concentration of boron in the root zone by evapotranspiration and subsequent leaching of the tanks to reduce the concentrations of boron and other salts. Accordingly, the normal calibration curves were used without adjustment, but with recognition that the resulting values might be small. Determination of changes in water content, as shown by differences in moisture rather than the

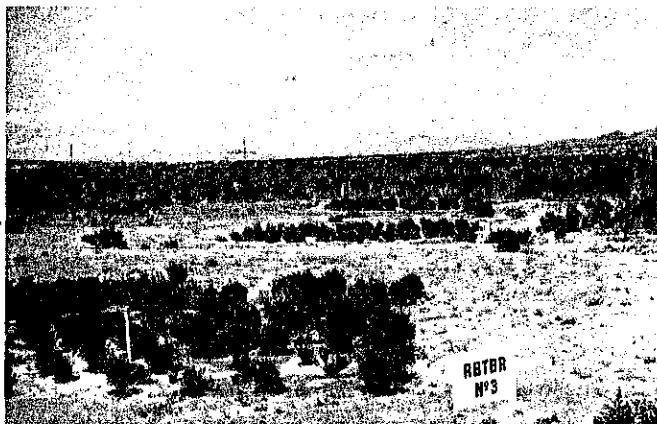


FIGURE 23.—Rabbitbrush tanks and access tubes installed for soil-moisture observations.

total content, was the principal objective. The effect of small errors on the seasonal water budget is minor.

#### WATER CONTENTS OBSERVED

Soil-moisture observations were made at the beginning, middle, and end of each of the growing seasons from 1962-67. Two additional sets of observations were made during the 1962 season and three in 1963. Post-season observations were made also in December 1963. Water-use evaluations for the first two seasons indicated that about one-half of the seasonal water use in the tanks had occurred by the end of July or early August. The summer observations therefore were scheduled usually for that time to provide a convenient mid-season check on tank operations and an index of midsummer moisture conditions.

The results of the spring and autumn observations during the 1962-67 seasons, in the individual tubes in the tanks and in the tube in the meadow area at the test site, are listed in table 10. The changes in water content occurring during the summer and winter periods are also indicated. The losses in the summer season indicate the part of the soil moisture that was discharged by evapotranspiration. These data and the tabulations in table 9 in the main report indicate that soil moisture supplied 26 percent of the total water used in the greasewood tanks during the study period, 15 percent in the rabbitbrush, 12 percent in the wildrose, and 8 percent in the willow tanks. The contributions varied widely from year to year owing to differences in plant growth, water level, and the availability of soil moisture. The changes in water content in the bare-soil tank were very small, and the soil-moisture contributions to the seasonal evaporation were minor.

The data listed in table 10 represent net changes in water content for the full profile sampled, although the principal depletions of soil moisture occurred in the unsaturated zone. Expression of the moisture contents

in terms of depth per unit of area permits ready comparison among tubes and tanks or with precipitation. The results are expressed in inches, but the seasonal water-use values were reported in equivalents of acre-feet per acre in the section on soil moisture and in table 9 in the main report.

Profiles of soil moisture in the tanks and the meadow at the beginning and end of each season are shown in figure 24. The water content is expressed in percent of volume, and the differences between the spring and autumn profiles delineate the zones of moisture depletion. The profiles for each of the four species of plants are composites of the data from several tanks and tubes for a particular species. The depths of water in the tanks shown also are average levels at the time of sampling; owing to variations in evapotranspirative draft and early season water-level adjustments, these depths may differ from the operating levels for the season. In 1964, the water content observed in the first foot of the capillary fringe above the water table in the tanks with plants was about 1 percent by volume greater in October than in April. This condition might have resulted from an increase in soil-moisture tension as available moisture higher in the capillary fringe was reduced by transpiration. The additional profiles shown for the meadow area represent the maximum and minimum conditions observed during the period September 1961–October 1967. The maximum occurred June 11, 1962, when flooding of the meadow caused essentially full saturation of the soils.

Winter precipitation was the principal source of water for replenishment of moisture in the soil above the capillary fringe. The annual replenishment varies widely as a result of variations in the type and rate of precipitation and opportunity for infiltration. The winter changes in water content shown in table 10 are a measure of the part of the winter precipitation that was stored during the nongrowing season. The remainder of the precipitation was lost by evaporation, some evapotranspiration, and sublimation of snow and ice.

#### WATER-CONTENT VARIATIONS IN 1963

Variations in the water content of soils in the evapotranspiration tanks during a typical season are shown by the seven sets of observations made in 1963. The water contents for the depths sampled in the tanks, expressed in inches depth per unit area, and the depths to water at the observation times are listed in table 11; the average contents are shown in figure 25. The September 4 observations showed the least content for the season, except that in the bare-soil tank. The increased content in October and December may be both the result of increase in capillary water above the water table on the

reduction or cessation of evapotranspirative draft and the result of small additions from precipitation. Capillary rise above the shallow water table in the bare-soil tank kept the surface soils moist. Evaporation of the small quantity of free water in these heavy soils caused a 1-foot lowering of the water table and a small reduction in total water content between October 20 and December 16.

#### WATER-CONTENT CHANGES IN SHALLOW FLOOD-PLAIN DEPOSITS

The flood-plain deposits in the Humboldt River valley provide storage space for large volumes of water in the ground-water reservoir and in the unsaturated soils near the land surface during floodflows. Water stored in these deposits during periods of rising river stage and released to the stream when the river stage falls is one of the principal sources of water that sustains low flows in the Humboldt River. The water may be stored as soil moisture in the unsaturated zone, including the capillary fringe, and as ground water in the saturated zone.

The discharge of water from the flood-plain deposits in areas where the water table is at shallow depth may occur by evaporation from the land surface, by transpiration from riparian and flood-plain vegetation—commonly woody phreatophytes—and by underflow to stream channels. All the water going into storage in a given season may not be released in the subsequent low-water season, or for several seasons of copious precipitation or heavy streamflow. The quantity of water stored or released seasonally, or carried over, may be substantial.

Data on changes in the water content of the flood-plain deposits have been obtained during the period 1962–67 at three sites in the Humboldt River valley; one is at the test site 4 miles southwest of Winnemucca, a second at Winnemucca, and a third at the Kearns Ranch 6½ miles northeast of Winnemucca. The access tubes at these sites permit sampling the soil profiles for depths of 81, 100, and 90 inches, respectively, which are adequate to cover the full range of the zone of soil-moisture change. Observations were made at the same intervals of time and depth as those in the evapotranspiration tanks.

Water-content profiles at these sites, based on five sets of observations made in 1962 as reported by Waananen (1965), showed seasonal changes in a year of high flow in the Humboldt River. Data obtained June 11, 1962, after the meadow had been flooded, represent the largest content observed during the study and indicate the water content of the soils under nearly full saturation. The initial measurement in September 1961

TABLE 10.—*Soil-moisture changes in evapotranspiration tanks at the*

Tank and tube	Depth of profile observed, in.	Water content and seasonal gain (+) or loss (—), in inches depth									
		Apr. 8-10, 1962	Change	Oct. 18-20, 1962	Change	May 1-2, 1963	Change	Oct. 20-21, 1963	Change	Apr. 13-14, 1964	Change
Greasewood											
1-A-----	81	22.16	—4.97	17.19	+4.71	21.90	—5.33	16.57	+1.78	18.35	—3.31
1-B-----	99	24.69	—3.91	20.78	+6.54	27.32	—5.47	21.85	+1.91	23.76	—4.73
1-C-----	93			16.62	+4.68	21.30	—5.45	15.85	+1.83	16.68	—2.22
1-D-----	93			19.90	+4.11	24.01	—4.71	19.30	+1.60	19.90	—2.02
Average-----	91½		—4.44		+5.01		—5.24		+1.28		—3.07
2-A-----	75	17.20	—3.65	13.55	+8.04	21.59	—6.44	15.15	+3.35	18.50	—4.63
2-B-----	99	26.81	—5.38	21.43	+6.93	28.36	—6.21	22.15	+3.16	25.31	—4.79
Average-----	87		—4.52		+7.48		—6.32		+3.26		—4.71
Rabbitbrush											
1-A-----	93	26.02	—1.03	24.99	—2.25	22.74	—2.37	20.37	+1.06	21.43	—1.99
1-B-----	87			22.70	—2.40	20.30	—3.01	17.29	+1.59	18.88	—2.65
	93										
2-----	93	26.94	—1.08	25.86	—2.89	22.97	—2.66	20.31	+1.41	21.72	—1.12
3-----	93	27.06	—1.25	25.81	—1.84	23.97	—2.78	21.19	+1.36	22.55	—1.40
Average-----	92		—1.12		—2.35		—2.71				—1.61
Willow											
1-----	60	22.09	—4.12	17.97	+2.62	20.59	—3.25	17.82	—2.18	19.52	—1.21
2-----	60	22.47	—6.11	16.36	+3.20	19.56	—3.32	16.24	+2.79	19.03	—2.76
3-----	60	22.15	—4.57	17.58	+3.35	20.93	—3.05	17.88	+2.47	20.35	—3.06
Average-----	60						—3.21				—2.34
Wildrose											
1-----	60	<sup>2</sup> 24.26	+0.09	24.35	—0.89	23.46	—1.62	21.84	+0.70	22.54	—1.26
2-----	60	<sup>2</sup> 23.48	—1.31	23.17	—1.98	22.19	—2.55	19.34	+1.29	20.93	—1.70
3-----	60	<sup>2</sup> 24.65	—1.82	22.83	—1.45	22.38	—3.19	19.19	+1.70	20.89	—2.44
Average-----	60						—2.45				—1.80
Bare soil											
	60	<sup>2</sup> 23.23	—1.72	21.51	+1.59	23.10	—0.39	22.71	+0.04	22.75	+0.37
Meadow											
	81	<sup>2</sup> 26.83	—5.59	21.24	+3.13	24.37	—3.32	21.05	+3.84	24.89	—2.52

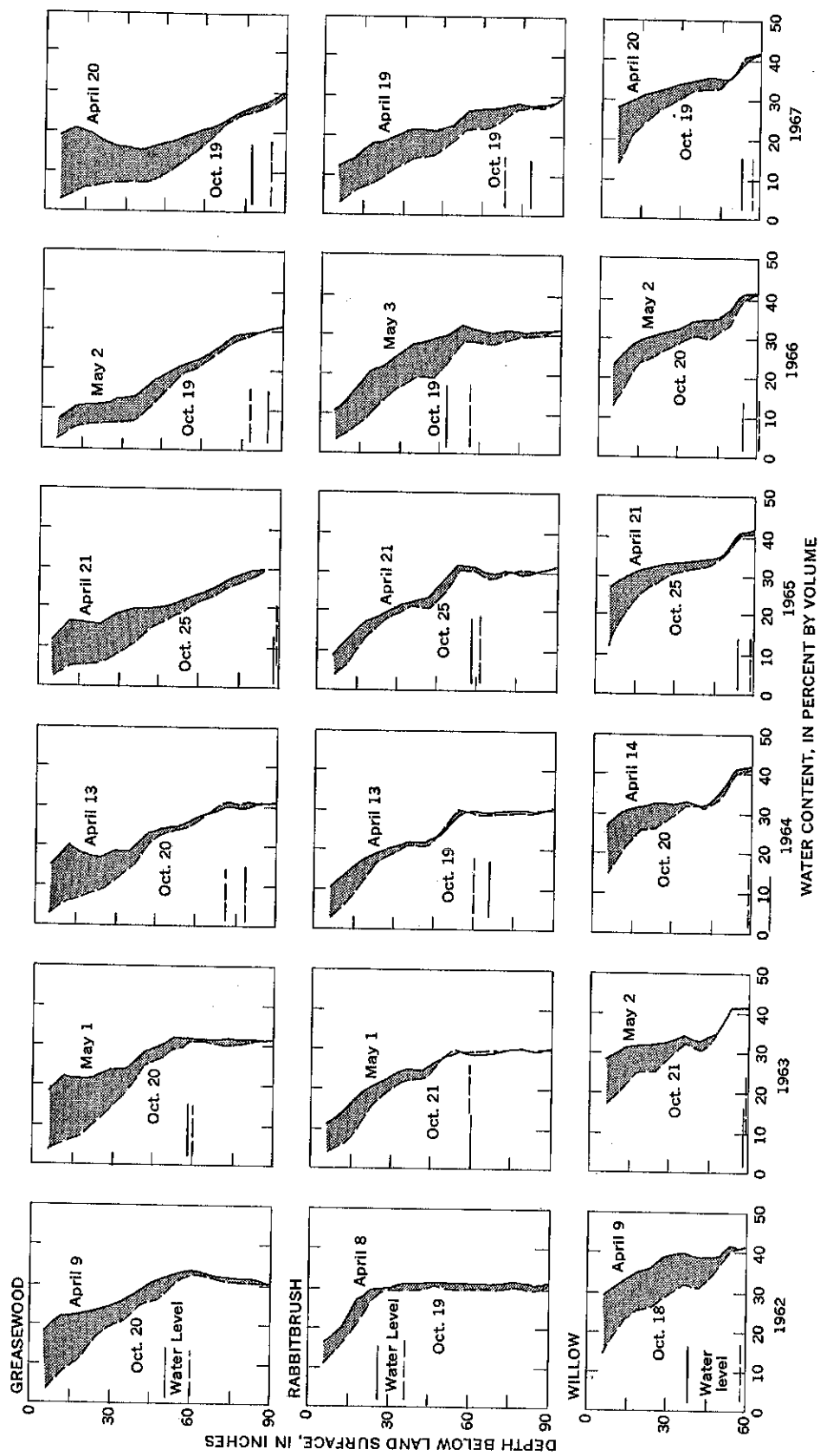
<sup>1</sup> Data not representative owing to puncture of tank membrane liner.<sup>2</sup> Change in depth of profile from 87 to 93 inches.

Winnemucca test site during summer and winter periods 1962-67

Water content and seasonal gain (+) or loss (-), in inches depth—Continued												
Oct. 19-21, 1964	Change	Apr. 20-21, 1965	Change	Oct. 25-26, 1965	Change	May 1-3, 1966	Change	Oct. 19-20, 1966	Change	Apr. 19-20, 1967	Change	Oct. 19-20, 1967
Greasewood—Continued												
15.04	+3.05	18.09	-5.14	12.95	+1.60	14.55	-3.32	11.23	+4.91	16.14	-5.27	10.87
19.03	+3.68	22.71	-6.15	16.56	+1.84	18.40	-3.39	15.01	+4.51	19.52	-6.50	13.02
14.46	+2.07	16.53	-4.13	12.40	+ .35	12.75	-2.08	10.67	+3.22	13.89	-4.62	9.27
17.88	+2.11	19.99	-4.63	15.36	+ .99	16.35	-2.59	13.76	+3.09	16.85	-4.22	12.63
+2.73		-5.01		+1.20		-2.84		+3.93		-5.15		
13.87	+3.61	17.48	<sup>1</sup> -7.72	<sup>1</sup> 9.76	<sup>1</sup> +4.49	14.25	-3.26	10.99	+5.36	16.35	-7.60	8.75
20.52	+4.14	24.66	<sup>1</sup> -9.40	<sup>1</sup> 15.26	<sup>1</sup> +5.59	20.85	-2.86	17.99	+4.97	22.96	-7.71	15.25
+3.88		<sup>1</sup> -8.56		<sup>1</sup> +5.04		-3.06		+5.16		-7.66		
Rabbitbrush—Continued												
19.44	+1.73	21.17	-2.64	19.03	+4.54	23.57	-7.19	16.38	+1.67	18.05	-4.06	13.99
16.23	+2.47	18.70										
		<sup>2</sup> 20.43	-2.98	17.45	+5.84	23.29	-8.46	14.83	+3.58	18.41	-5.48	12.93
20.60	+2.00	22.60	-1.69	20.91	+3.05	23.96	-3.33	20.63	+1.82	22.45	-4.40	18.05
21.15	+2.12	23.27	-1.04	22.23	+2.39	24.62	-4.30	20.32	+2.03	22.35	-6.23	16.12
			-1.76				-5.15				-5.13	
Willow—Continued												
18.31	+1.85	20.16	-3.45	16.71	+1.68	18.39	-3.30	15.09	+3.99	19.08	-3.05	16.03
16.27	+3.37	19.64	-1.75	17.89	+2.21	20.10	-2.65	17.45	+3.58	21.03	-2.90	18.13
17.29	+3.44	20.73				21.82		12.70	+3.48	16.18		
Wildrose—Continued												
21.28	+1.54	22.82	-1.17	21.65	+0.65	22.30	-2.27	20.03	+2.12	22.15	-2.56	19.59
19.23	+2.46	21.69	-2.18	19.51	+3.39	22.90	-2.84	20.06	+2.55	22.61	-1.87	20.74
18.45	+2.78	21.23				22.58		14.11	+4.82	18.93		
Bare soil—Continued												
23.12	-0.66	22.46	+0.09	22.55	-0.80	21.75	-0.42	21.33	+1.25	22.58	-0.99	21.59
Meadow—Continued												
22.37	+4.56	26.93	-1.86	25.07	+3.63	28.70	-13.51	15.19	+4.65	19.84	+0.34	20.18

<sup>1</sup> Apr. 4, 1962.

## STUDIES OF EVAPOTRANSPIRATION



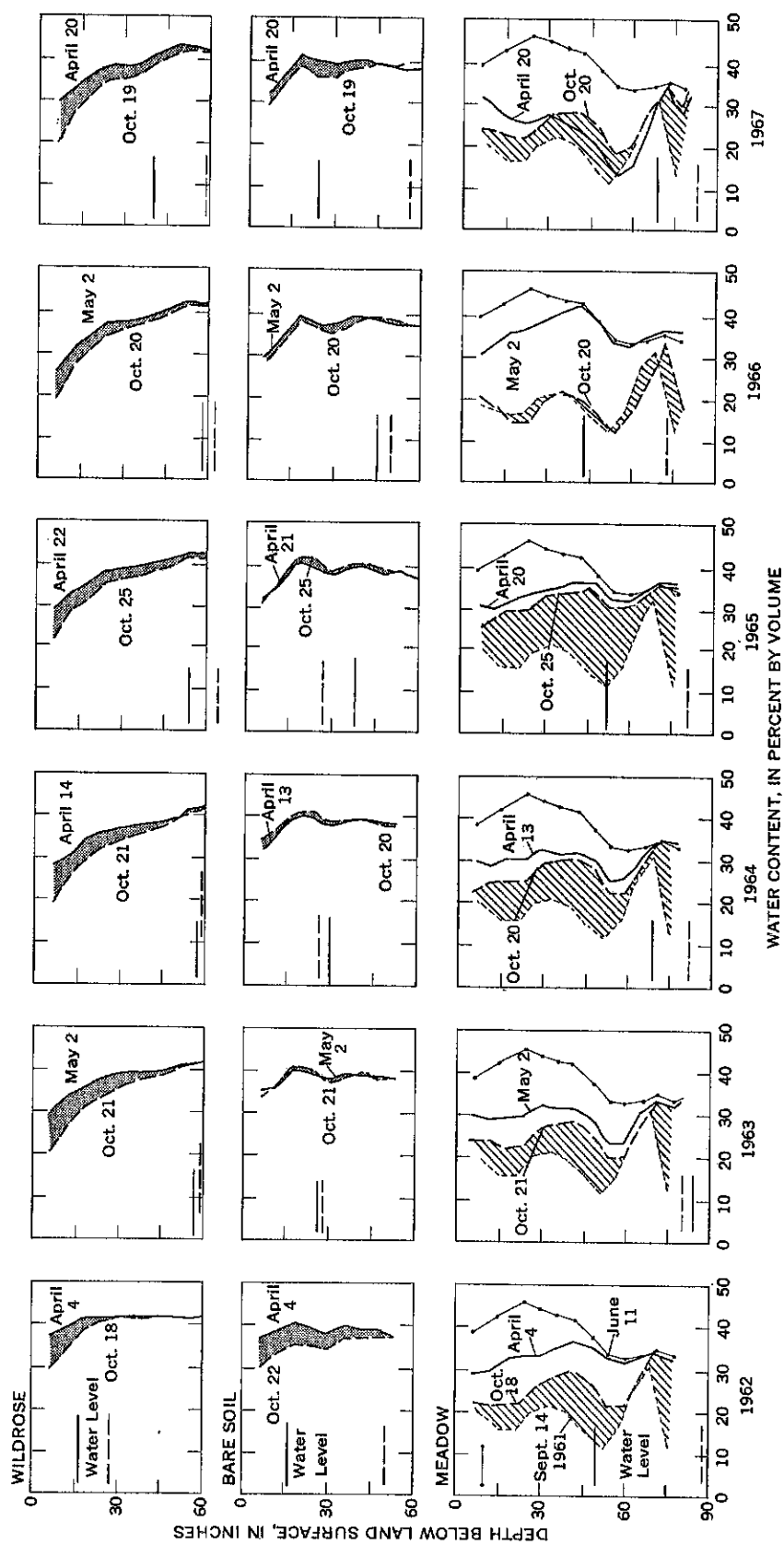


FIGURE 24.—Soil-moisture profiles at the beginning and end of the growing seasons 1962-67 in evapotranspiration tanks and the flood plain at the Winnebago test site. Shaded areas on profiles in the tanks indicate seasonal changes in water content. Shaded areas for meadow profiles indicate difference between end-of-season water content and minimum content September 14, 1961. Meadow profile for June 11, 1962, is the maximum observed and represents nearly full saturation of the soils.

in the meadow area at the test site fortunately provided information on the water content at the end of a 3-year dry period, thus perhaps representing the minimum that might be expected.

The water content observed at the end of each season from 1961 to 1967 at the three sites is shown in figure 26, together with the maximum content as observed in June 1962. These data demonstrate that the storage in the

flood-plain deposits increased more than 1 acre-foot per acre between September 1961 and June 1962, but in October 1962 only about one-half acre-foot per acre of this increase still remained in storage. In subsequent seasons the storage increased slightly, but in the dry season of 1966 the soil moisture was depleted to the 1961 levels; in 1967 the storage increased again, but less than one-half acre-foot per acre.

The distribution of moisture in the soil profile in the meadow area at the test site is shown in figure 24. The profiles for September 1961 and June 1962 are repeated in each graph to indicate the relation of the water con-

TABLE 11.—Water content of soils in evapotranspiration tanks at the Winnemucca test site, as observed during the 1963 season

Tank	Depth of profile observed (in.)	Water content, in inches depth (upper number) and depth to water, inches below land surface (lower number)						
		May 1-2	June 11	July 1	July 26-27	Sept. 4-5	Oct. 20-22	Dec. 16-17
Greasewood								
1.....	91½	23.63	22.10	21.26	19.23	18.00	18.39	17.53
		59	60	60	60	60	60	91
2.....	87	24.98	23.41	22.53	19.53	18.26	18.65	19.52
		57	60	60	60	60	60	72
Average water content.....	90	24.30	22.76	21.90	19.38	18.13	18.52	18.52
Rabbitbrush								
1.....	90	21.52	20.83	19.92	18.48	18.54	18.83	18.87
		61	60	60	60	60	60	74
2.....	93	22.97	21.91	21.38	19.57	19.81	20.31	19.87
		59	60	60	60	60	60	71
3.....	93	23.97	23.39	22.44	21.17	20.65	21.19	21.07
		61	60	60	60	60	60	72
Average water content.....	92	22.82	22.08	21.25	19.74	19.67	20.11	19.94
Willow								
1.....	60	20.59	20.17	19.97	16.51	17.34	18.11	
		56	60	60	60	60	60	(1)
2.....	60	19.56	19.27	19.07	15.52	16.24	16.94	
		57	54	60	65	62	63	(2)
3.....	60	20.93	22.76	24.03	20.19	17.43	17.88	18.90
		61	25	62	64	61	61	(3)
Average water content.....	60	20.36	20.73	23.84	19.74	16.49	17.15	17.98
Wildrose								
1.....	60	23.46	22.95	24.00	23.05	21.12	21.84	22.12
		59	60	60	59	61	61	76
2.....	60	22.19	22.75	23.96	21.96	19.12	19.04	20.35
		56	30	69	69	62	63	77
3.....	60	22.38	21.99	24.38	22.58	18.77	19.19	19.09
		55	48	60	56	62	62	79
Average water content.....	60	22.68	22.56	24.11	22.53	19.67	20.22	20.72
Bare soil								
	60	23.10	22.82	22.72	22.27	22.16	22.71	22.00
		20	18	23	28	28	28	40

<sup>1</sup> Inlet tube dry.

<sup>2</sup> Tanks flooded; water content from 1962 data under full saturation.

<sup>3</sup> Dry.

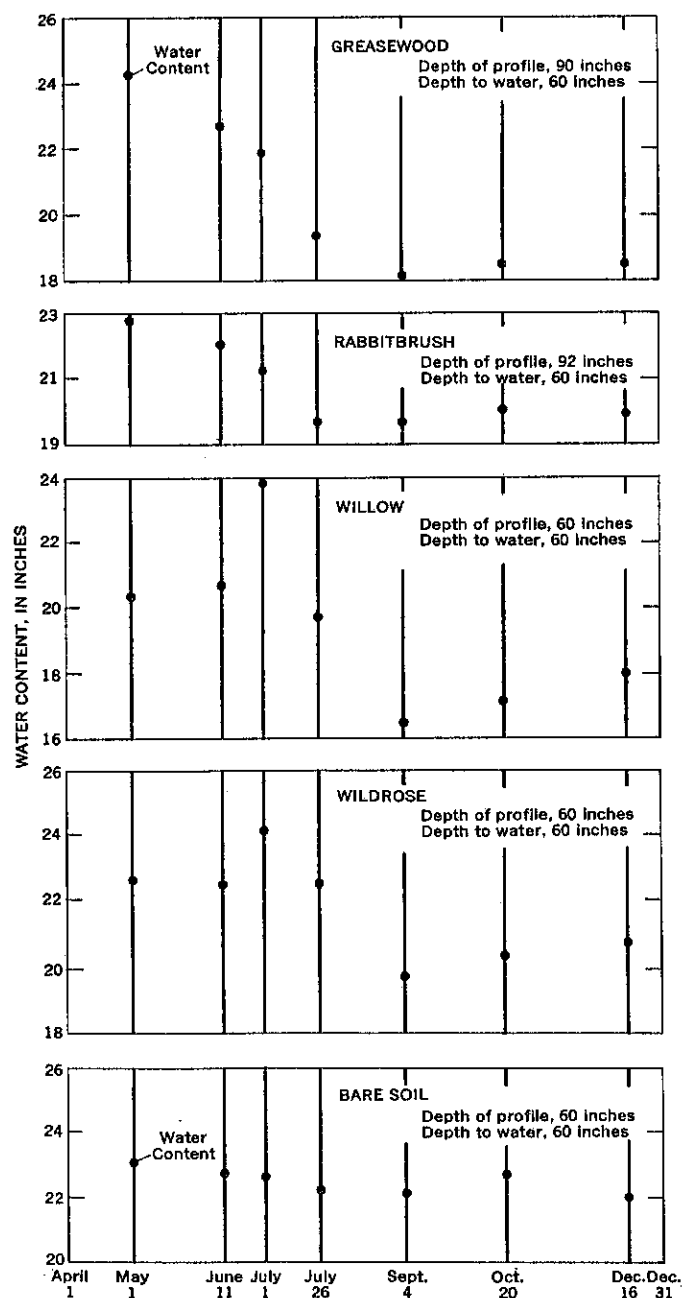


FIGURE 25.—Variations in water content of soils in evapotranspiration tanks at the Winnemucca test site during the 1963 season.

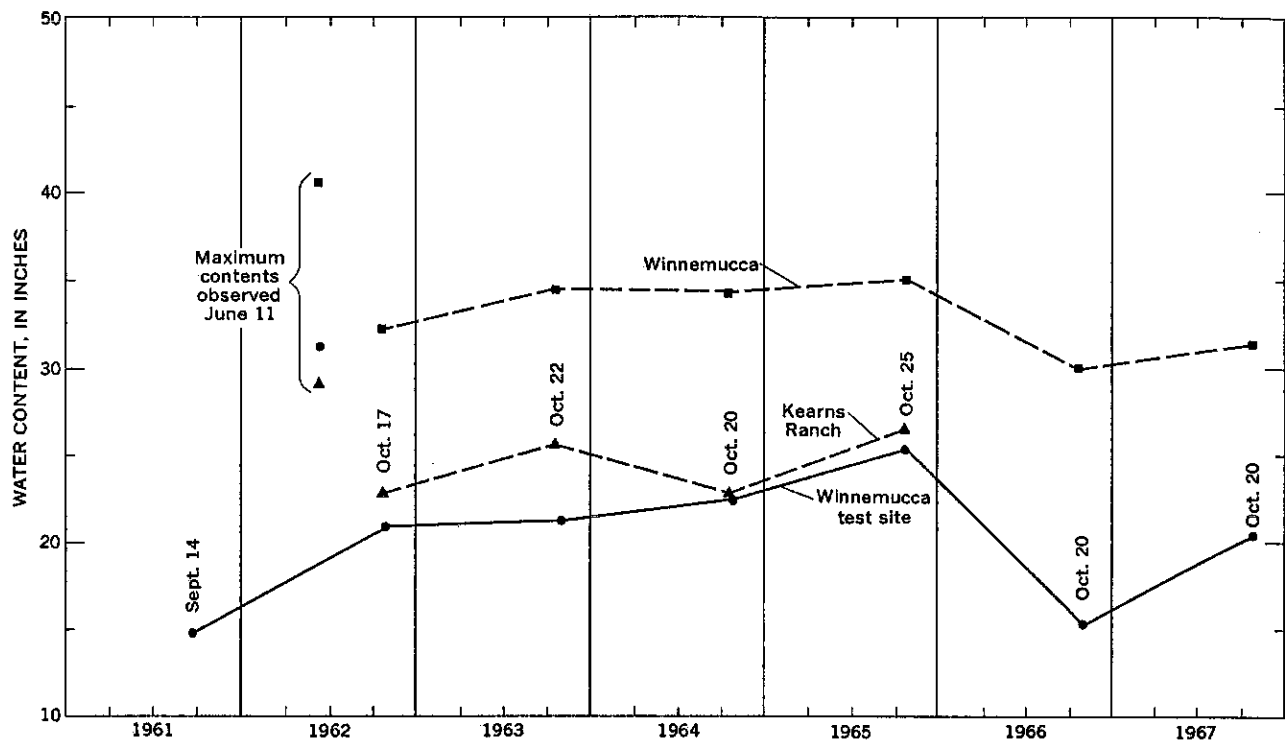


FIGURE 26.—Water content at end of each season and maximum content observed in June 1962, in inches, as observed at three sites in Humboldt River flood plain near Winnemucca, Nev.

tent each spring and fall with the extremes observed. The shaded areas indicate the distribution in the profile of moisture in excess of the minimum storage. The October 1966 data differ slightly from those for 1961 because the initial observations were taken at different depths.

It might be inferred from the slight increase in the October water content from 1963 to 1965 that water storage in the flood-plain deposits had only a minor effect on the annual water budgets for the Humboldt River in those years. The large storage increase in 1962, sharp decrease in 1966, and lesser gain in 1967, however, when related to the full extent of the flood plain affected in the basin, may represent significant differences in the relation between annual precipitation and streamflow, as well as in the water available to plants on the flood plain. The depletion of soil moisture and ground water in 1966 may have resulted in a larger sustained summer flow in the Humboldt River than would have been produced by the annual precipitation alone, whereas the increased retention in 1962 and 1967 reduced the streamflow.

The seasonal water-content determinations thus provide an index of storage capacity and a means for estimating the volumes of water that could be accepted by and stored in flood-plain deposits during subsequent floodflows, or that would be effective in maintaining streamflow during dry seasons.

## REFERENCES

- American Society of Civil Engineers, 1962, Nomenclature for hydraulics: Am. Soc. Civil Engineers Manual No. 43, 501 p.
- Cohen, Philip, 1965, Water resources of the Humboldt River valley near Winnemucca, Nevada: U.S. Geol. Survey Water-Supply Paper 1795, 143 p.
- Horton, J. S., Robinson, T. W., and McDonald, H. R., 1964, Guide for surveying phreatophyte vegetation: U.S. Dept. Agriculture, Forest Service, Agriculture Handbook 266, 37 p.
- Lee, C. H., and others, 1926, Evaporation on the United States Reclamation Projects: Am. Soc. Civil Engineers Proc., August 1926, p. 1196.
- Oertli, J. J., 1964, Loss of boron from plants through guttation: Soil Science, July-December, v. 94, p. 214-219.
- Pacific Southwest Inter-Agency Committee, Phreatophyte Subcommittee, 1966, Glossary of terms relating to the phreatophyte problem in Vegetation management on flood plains and riparian lands—symposium presented by the Phreatophyte Subcommittee at 66-3 meeting of the Pacific Southwest Inter-Agency Committee, Albuquerque, New Mexico, Aug. 30, 1966, p. 48-54.
- Sondregger, A. L., 1929, Water supply from rainfall on valley floor: Am. Soc. Civil Engineers Proc., v. 55, no. 5, p. 1139-1165.
- Tomanek, G. W., and Ziegler, R. I., 1962, Ecological studies of saltcedar: Div. Biological Sciences, Fort Hays Kansas State College, Fort Hays, Kansas, 128 p.
- Waananen, A. O., 1965, Water-content changes in shallow flood-plain deposits at three sites in Water resources of the Humboldt River valley near Winnemucca, Nevada: U.S. Geol. Survey Water-Supply Paper 1795, p. 104-108.